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AIRPORT SITE SELECTION USING MULTIPLE-CRITERIA DECISION ANALYSIS: THE CASE OF NEW LISBON AIRPORT

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ABSTRACT

Current Lisbon Airport has been considered for many years as not corresponding to future demand expectations. The last 60 years have been marked by Portuguese government uncertainty and inconsistency and heated debate about a New Lisbon Airport location. This work is focused on airport site selection using multiple-criteria decision analysis applied to the case of New Lisbon Airport. The main objective is to apply a new methodology to the solving of this problem. Results show how the options studied performed on different aspects and what is the preferred location that best suits the necessity for an international airport in Portugal.

Keywords: Airport Operations, Airport Site Selection, Multi-Criteria Decision Analysis, New Lisbon Airport

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1. INTRODUCTION

1.1. CONTEXT HISTORY

Lisbon Airport is the main international airport in Portugal and is situated 6 km of city centre. Opened back in 1942 in Portela, which was just at the northeast of the city, the airport has been pressured by the fast-growing expansion of the Portuguese capital. This urban expansion restricted further expansions of the infrastructure. During the last 50 years a possible expansion or a new location for the Lisbon Airport has been the source of debates of Portuguese government with the population and local communities. On the wave of rapid population and economic growth during the 1960s, an expansion to the airport was proposed (Partidário and Coutinho 2011). However, the Lisbon location was not considered as it was already too close to the city. Instead, a new location site was necessary to find. In 1971 five alternative sites were find, all of them on the south bank of the Tagus river. Rio Frio location was chosen, motivated by the new bridge built between the two banks of the river and by the location's greater space, smaller distance, and higher accessibility. The first oil crisis during the 1970s, and the Carnation Revolution that led to political changes in the country and consequent economic decline meant that this option was not implemented and the project for the New Lisbon Airport (NAL) was put behind more important issues. In 1982 the new government returned to the issue, now with 12 options to choose from. This time Ota, located 50 km north of city centre of Lisbon, was chosen. As Portugal was recovering from turmoil during the 1970s, the project did not advance due to lack of funds. The subsequent integration of Portugal into the European Community allowed a reconsideration of the issue in 1990. This time a third option, from the left bank of Tagus, was added to Rio Frio and Ota. Shortly after, the third option was abandoned. All these years only geographic, engineering, and economic issues were given attention. After more than 30 years, it was only at the end of the 1990s that environmental issues were given importance (Partidário and Coutinho 2011). From 1990 on a new Environmental Impact Assessment (EIA) was mandatory to accept a project. Two separate EIA studies were performed on Rio Frio and Ota locations, ignoring an eventual comparative analysis. Again, Ota was chosen as Rio Frio would lead to tree felling of 50,000 cork trees, and due to its closeness to protected areas. Despite the strong economic factor of the location of Ota in a highly populated area between Lisbon Metropolitan Area and Porto Metropolitan Area, its limitations, related to hydrologic, meteorologic, and engineering conditions, were evident, and originated heated debate among politicians, general public and stakeholders. While the design for the Ota project was being developed, two studies – one by the Confederation of the Portuguese Industry (CIP) (CIP 2007a) and one by the National Laboratory of Civil Engineering (LNEC) (LNEC 2008) – concluded that the best option was instead a Field Firing Range in Alcochete (Fig. 1). Eventually the new Portuguese government changed its preference from Ota to the new location in 2008 (Conselho de Ministros 2008). Similar to the 1970s, a new financial crisis erupted during 2007-2008, which implied cost-cutting measures from the government and dismissal of the new project. Only in 2019, after several years of economic recovery, a new plan, commonly known as Portela+1, to expand Lisbon Airport and maintain it as the main in the country and build a new one on the south bank of Tagus location of Montijo, being it a secondary airport for low-cost companies, was unveiled by the government.

1.2. DECISON-MAKING PROCESS AT *NAL*

Since the first iteration of a proposal for the *NAL* location during the 1960s until the present day, all these 60 years were marked by constant uncertainty and inconsistency from Portuguese governments. It could be explained by frequent political and economic changes in Portugal. However, if we go deeper into explaining its real cause, we can perceive that the reason is actually the decision complexity that involves the relocation of such an impacting infrastructure as an international airport. The decision process complexity consists of four major dimensions: political, institutional, economic, and financial. Political, because there are several places involved that are affected by the decision process, such as Lisbon, the chosen location and other alternative locations considered, and that could increase the tension between them (Gonçalves and Marreiros 2014). By changing the airport from Lisbon to other location, the political strength will switch from some politicians to others. Institutional, because there are several different opinions of government, opposition, local government, and general public. Differences of opinion between different governments over the years, differences between central and local government, and differences inside the government. Economic, because of the relocation of airport demand and employment and the relocation of development which could impact the general economic picture. Financial, because of the involving risks of such a costly investment and the consequent opportunity costs of ignoring the alternative options. Furthermore, Portugal belongs to the group of countries with volatile financial market (Gonçalves and Marreiros 2014).

1.3. PURPOSE

The main purpose of this thesis is to apply a new methodology to solve the long-standing problem of the *NAL* location: multiple-criteria decision analysis (MCDA). Such analysis will be performed by exploring the functionalities of MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) software. As mentioned before, airport site selection is a complex decision-making process, which consists of identifying the best option among a long list of potential alternatives. The aim here is to narrow this list to four options that will be studied in detail. Another goal is to identify and choose from a list of different criteria covering different aspects of airport operations those that are more important in this context. One specific target is to understand which criteria have more importance and should be given more weight, and which are decisive but not the most impacting. By gathering the most correct data and applying it to the model created, the main questions to answer are: "How good will each of the four options perform in each criterion?"; "What will be the overall performance of each option?"; "Which options are more preferable and which not?".

1.4. SIGNIFICANCE

Nearly 60 years have passed since the first site survey for the *NAL* was carried out. But even after so much study, research and debate no consensus was reached. As pointed out by ANAC (2016), demand increase is expected during the next years at the Lisbon Airport, which means we are getting closer to the point where actual capacity will not fit the expected future demand. Adding to this the existing safety and environmental issues of the actual infrastructure, it is evident that a new location is necessary for the main airport in the country. Hence, it is critical to take the risk and make the decision. Until now, no study has focused on the use of MACBETH, as a multiple-criteria decision analysis tool, to solve the problem. By conducting such a research, a new perspective is added to the multiple existing and by adding a new point of view, we could get closer to the much-expected consensus.

2. LITERATURE REVIEW

2.1. AIRPORT MANAGEMENT

Airports are complex transports systems, where a wide range of facilities and services are present, that are managed by a huge variety of players. Each airport issue is managed differently and depend mainly on the type of ownership, management structure and style, degree of autonomy, and funding. While airports have traditionally been owned by governments and most flights were national, it has now moved to privately owned airports by international companies (Graham 2014). This change has had a great impact on airport economics, the way it is measured, and the alternative methods used to benchmark airport performance. It has also changed the way airport operator and airlines relate. Despite having distinct goals and trying to achieve more control over airport management, their relationship is critical to the overall airport success. The competitive environment of the airline industry has forced airport operators to serve the needs of different types of customer and the regulatory developments and technological innovations have changed the processes' provision. Airport service quality and passenger experience is perceived differently by diverse customers and future demand may not be the same. Therefore, airports should understand what the customer perception about its service quality is and which factors are determinant to the ever-changing demand patterns. Major changes have happened with airport revenues where besides traditional revenues from tickets, non-aeronautical or commercial revenues have had growing importance. The change in ownership structure has changed the competitive environment from monopoly to competition, and the price and quality management approach, and has created the need for airport marketing. A long-standing problem of airport management has been the trade-off between economic benefits and social impacts for the regional or national community, and environmental protection of local communities (Graham 2014). As the past has shown the airport industry has always been present in a volatile and unclear environment and everything indicates that the situation will be similar in the future and airport managers should be prepared to deal with unexpected circumstances.

2.2. AIRPORT OPERATIONS

Managing airport operations is a complex system of interconnected activities, where three main elements interact: the **airport**, the **airline**, and the **user** (Ashford et al. 2012).

Demand peaks and flight scheduling: airports are one of the busiest modes of transport, where peaks in demand are very common. While there are very different demand levels, it is essential to distinguish these by time, because different time ranges imply different management and decisions. Daily peaks and hourly peaks depend on the decisions taken about staffing and physical facilities, while monthly peaks and annual variation depend on the long-term planning of airport capacity adjustment. Conflicts between airport operator and airline could show up. While the airport operator aims to spread the demand over the whole day in order to take the pressure out from facilities capacity, the airline aims to maximize fleet utilization and load factors by scheduling more flights during peak times (Ashford et al. 2012). An option to lead with demand peaks is **de-peaking**, which means spreading flights more evenly over time. There are three strategies of de-peaking that could be applied (Fig.2). The scenario where demand is completely even throughout the day is totally unrealistic, hence it only exists theoretically. The first possible strategy is the one where large schedule changes are made. Each peak is specified with a maximum level of workload, and effort is put to reduce each peak to that level by transferring the workload with varying percentage to different times. The second practical strategy is the most realistic and involves smaller schedule change with equivalent percentage of transfer in each peak (Luethi, Kisseleff and Nash 2008).

Airport access and security: while in the past the responsibility of airport access was put on urban planners, nowadays airport operators understand that airport efficiency and performance depend on its involvement in airport access and transport systems planning. There are three types of airport users: passengers, employees, and visitors, and each one has varying characteristics and requirements. Due to increasing traffic congestion and environmental degradation, airports have improved road capacity for private vehicle access modes such as automobile and taxi and invested in public transport access modes such as train, metro, and bus (Budd, Ison and Ryley 2011). In the past, security was not considered a serious issue due to low occurrence of crime incidents. However, several harmful terrorist acts such as 9-11 have served as precedent to increase airport security and take measures such as passenger, luggage, freight, and cargo search and screening, access control within and throughout airport buildings, vehicle access identification, and perimeter control (Ashford et al. 2012).

Passenger and cargo terminal operations: before entering the aircraft, passengers and cargo are required to pass through several stages at the respective terminal. At departure, the flow process starts at the check-in and bag drop area where passenger handling and luggage handling are separated, and is followed by security control, passport and customs control, gate control and boarding. At arrival, the flow is continued by transfer check-in if required, health control if required, passport and customs control, and finished by luggage claim. Domestic flights flow process differs from international flights. There are five distinct passenger terminal activities: direct passenger services, airline-related passenger services, airline-related operational functions, governmental activities, and non-passenger-related airport authority functions. Cargo terminal is divided into import operation and export operation. On the import side, the flow process consists of cargo input, sortation, check-in, storage, processing, and delivery. On the export side it consists of shipment receipt, processing, storage, assembling, and loading. (Ashford et al. 2012).

Ground and luggage handling: an aircraft while parked in the apron is served by a mix of staff from airport operator, airline, and handling agencies (Fig. 3). Passenger handling is the processing of passengers in the terminal, in the apron, and in the aircraft performed exclusively by each airline. It consists of ticketing, check-in, luggage handling, and among others passenger loading and unloading. Ramp handling is performed exclusively in the apron and involves the aircraft directly. It consists of marshalling, towing, fault repairing, fuelling, wheels and tires inspection, ground power supply, de-icing and washing, cooling/heating, onboard servicing, catering, etc. Luggage handling is a specific aspect of ground handling that involves luggage drop at departure airport, screening, storage, loading/unloading, and reclaim at arrival airport. Most flight delays are directly related to ground and luggage handling, and whereas this function is responsibility of airlines, it is given great importance (Ashford et al. 2012).

Operational readiness and aerodrome technical services: every airport should be prepared and have the required operational facilities available and ready to serve its customers and allow aircraft making flights. Aircraft fly under several constraints such as visibility, which depends on weather conditions and traffic density, crosswind effects, which depends on wind conditions, and bird strike. Therefore, airports should have the required runways and environment to control these constraints under different degrees of severity. Pavement surface should always be clean and free of any contaminants and debris by assuring regular airfield inspections. Maintaining readiness requires a system of maintenance management which is composed of preventive maintenance and electrical maintenance. It also ensures readiness in case of aircraft rescue and firefighting, and airfield construction. Technical services such as air traffic control, telecommunications, meteorology, and aeronautical information are necessary activities concerning safety control, navigation and communications, and information (Ashford et al. 2012).

Noise control and sustainable development: noise from aircraft is one of the most significant airport problems and an unavoidable by-product. While single-event metrics quantify the worst single noise event, it is not enough to measure the whole impact of noise. Cumulative-event metrics take in consideration the general level of annoyance and interference (Min, Lim and Mavris 2015). To operate in accordance with regulations, several strategies have been developed to control noise: deploying quieter aircraft, using noise-preferential runways, insulation and land purchase, operational noise-abatement procedures during take-off and approach, etc. Many airports have curfews with complete ban of night flights, while others have permission for some lower-noise aircraft, quota of night movements or exemptions to delayed flights. Any of these measures increases the problem of peaking. Noise contour maps with categories of noise exposure are developed according to noise compatibility of functional areas to aid the land use (Fig. 4). While noise impact is the most concerning aspect of sustainable development at airports, there are other issues that should be considered such as gas emissions and air quality, carbon emissions, energy and water consumption, solid waste generation, and water pollution (Ashford et al. 2012).

2.3. AIRPORT SITE SELECTION

Although site selection process may vary between airports, generally it includes three steps (Horonjeff et al. 2010). The first step is **identification**, where a shortlist of sites is identified from all the potential ones by meeting the specific criteria for this step. In **screening**, the selected sites go through a comparison assessment by using criteria that at least should include operational capability, capacity potential, ground access, development costs, environmental consequences, socioeconomic factors, and consistency with areawide planning (Ashford, Mumayiz, and Wright 2011). In **selection**, the final option is chosen and may also include weighting the criteria. Weighting criteria frequently involves subjective judgement, and in many assessments, it is avoided, and all the criteria are given the same weight. Alternatively, performing sensitivity analysis on weights or designating a voting committee could remove arbitrariness from weighting. Both the expansion or modernization and the construction of new airport is part of the concept called airport master plan (Fig. 5). Its goal consists of guiding the future airport development taking into consideration future demand levels, environmental aspects, local community development, and others. Decisions of airport site selection or expansion are frequently source of debates and controversy, as it has significant impact on the social, economic, and environmental situation. Every airport site selection project involves trade-offs between economic and environmental objectives. While a new airport could bring economic benefits by satisfying the airport demand growth, it brings harm to local residents with increased noise and greenhouse emissions, worse air quality, etc. This brings to local impact and two distinct attitudes towards the project. NIMBY or "Not in my backyard" is a negative attitude that is consequence of its environmental harm. PIMBY or "Please in my backyard" is a positive attitude that is consequence of its economic benefits. This is a challenge that the airport site selection process involves along with the risks and uncertainties, and the difficulty to choose and compare the different approaches to analysis of airport site selection options. The long-term horizon and the irreversibility of an airport investment may create differences of expert view and risk aversion of local stakeholders. There are two main approaches to analyse airport site selection options: multi-criteria analysis (MCA) and cost-benefit analysis (CBA). In MCA, the criteria to judge the options are those that the stakeholders are most concerned with and are directly linked with the most important issues of the project. Each project has its unique set of criteria which are chosen by its stakeholders. The options are assessed qualitatively rather than quantitatively on those criteria, and hence the stakeholders could be induced to unintentional cognitive bias and to inaccurate judgement. While MCA's main disadvantage is its relative subjectivity, its main advantage is that it is straightforward and easy to understand (OECD/ITF 2017). In CBA, the main objective is comparing the costs and benefits of a project measured in monetary units. In general, it means the total value that it brings to the society and consists of quantifying the positive impacts and the total costs of provision and choosing the option where benefits outweigh costs the most. Contrarily to MCA, that can show the degree of equity of a project, that is who wins and who loses more in different aspects, CBA can show only the degree of efficiency, by assessing the value for the whole society, not individually. While the CBA approach is more common in airport expansion projects, there is always the possibility to combine the two ones into a mixed one, by taking the advantages of one to eliminate the disadvantages of other. There are some conclusions that can be drawn about airport site selection: new project should only start after examining the need of a new airport, and taking in consideration that there are other options besides expansion or building; options should be assessed in a comparable manner, not individually; assessment criteria should consider all impacts, positive and negative, and all interested parties in the matter, to identify who wins and who loses from the project and how much; risk and uncertainty should be included as an assumption and scenarios should be prepared taking into account different forecasted airport demand; the process should involve all the stakeholders, that should be clearly informed about all the issues and trade-offs involved (OECD/ITF 2017).

2.4. MULTI-CRITERIA DECISION ANALYSIS

The main principle of multi-criteria decision analysis (MCDA) consists of a set of decision-makers setting objectives for the decision-making process, developing a required set of criteria associated to that objectives, making judgements about the options on those criteria, deciding on the criteria's weights, and making preferences between options. Besides the subjectivity of decisions, MCDA does not display which costs and benefits the options imply and which option is more valuable for the society. A performance matrix is a required feature of a MCDA process, where rows consist of options and columns consist of criteria, and where each option is judged on each criterion quantitatively or qualitatively (Dodgson et al. 2009). Common features are also scoring and weighting. Experts in each field related to the criteria make their inputs with judgements about options on a predefined scale, where the lowest value means an option is the least preferred and the highest value means an option is the most preferred on certain criterion. Criteria are given weights to define which are more important. Coherence is expected in a MCDA process, where transitive relation between options should be present. For instance, if *a* is preferred to *b*, and *b* is preferred to *c*, then *a* is preferred to *c*. While following such rule would lead to a more rigid option preference, performing a sensitivity analysis could bring a more flexible result (Barfod and Leleur 2014). There is a wide range of different MCDA techniques. Even though there are problems where an infinite number of solution options exist, most of situations deal with finite number of alternatives. All the techniques start with a performance matrix, but the difference in methodology is determined by the principles they use to process the same information. Some of the techniques include direct analysis of the performance matrix, multi-attribute utility theory, linear additive models, the Analytical Hierarchy Process (AHP), outranking methods, procedures that use qualitative data inputs, methods based on fuzzy sets, SMART, REMBRANDT, MACBETH and MAUT. The MCDA is useful by overcoming the difficulty of translating judgements into numbers by allowing subjectivity and by making use of quantitative and qualitative indicators; by allowing the participation of stakeholders as decision makers; and by addressing equity concerns by identifying the most benefited and harmed. However, it is vulnerable by assessing only the comparative and not the independent performance; by being time and resource intensive due to its participatory nature; and by its difficulty in eliciting criteria weights (MOTOS 2007). A typical MCDA process involves **8 steps**. **Step 1** requires problem and decision process contextualization, establishing the objectives to be achieved, assigning the key players and decision makers and the extent of their contribution, deciding the form of MCDA to be used, and conducting SWOT and PEST analyses. **Step 2** is identification of all possible options and sieving to the best suited according to some specific criteria. **Step 3** is identification of criteria for assessing the consequences of each option, where detailed objectives are identified and translated into specific measurable criteria. Those criteria that are interrelated could be clustered into a hierarchy of criteria groups, called value tree, that are linked to a broader aspect. **Step 4** involves scoring. First, consequences of each option on each criterion are described qualitatively by building a performance matrix. Second, consequences are described quantitatively by building relative preference scales to score the options on the criteria. Last, consistency of scores is checked to validate results. **Step 5** is weighting where each criterion is given weight which reflects its relative importance to the decision. A common method is swing weighting where weights are decided based on the difference between the least and the most preferred option on each criterion. **Step 6** is calculating overall weighted scores for all options by summing the products of option's score on each criterion and the corresponding criterion's weight. **Step 7** is examining the results and analysing the general findings and conclusions. **Step 8** is conducting a sensitivity analysis, to find if a change in the scores or in the weights can have an impact on the result, and to find if other possible options should be considered (Dodgson et al. 2009).

3. RESEARCH APPROACH

3.1. RESEARCH QUESTION AND METHODOLOGY

This research is an analysis study where Multiple-Criteria Decision Analysis (MCDA) methodology is applied, by making use of a particular tool, to answer the following research question: "which is the best location for the New Lisbon Airport (NAL)?". It will involve screening the suitable solution options, appraised by applying a set of criteria, collecting the necessary data, making the calculations by using an MCDA-specific tool, examining and analysing the results, making conclusion, and giving recommendations. Based on methodology that international airports use to choose site selection (OECD/ITF 2017), two different types of analysis were available: MCDA and CBA. It is important to mention that in this research two types of options that can serve as solution are present: "same location with expansion" and "new location". A MCDA type of framework is typically applied in comparing alternative sites for new location, while CBA is more applied in comparing alternative sites for expansion location. (OECD/ITF 2017) As several new location options and just one expansion option are considered to study in this research, *a priori* the MCDA technique is more preferable to use.

3.2. RESEARCH DESIGN

The research consists of performing a mix of quantitative and qualitative analysis. It involves assessing certain options in a set of criteria or variables. The result of the research is a set of individual overall airport performance results that are organized to form a ranking of options preference. Overall airport performance is a dependent variable of several independent variables (criteria). The several options are going to be assessed quantitatively, qualitatively, and using direct ranking of alternatives in a set of hierarchically clustered criteria. Some aspects are more suited to be assessed through a quantitative scale, others are more difficult to quantify and by assessing through a qualitative value scale it is possible to quantify them. Some aspects are too ambiguous to be assessed, and thus they are appraised through a ranking. Data used was gathered from several sources such as studies, articles, journals, maps, databases, news, pictures, and others.

3.3. INSTRUMENTS

A set of suitable MCDA and other instruments were available to aid the research. From a long list of options, Measuring Attractiveness through a Categorical-Based Evaluation TecHnique (**MACBETH)** was chosen as it provides a humanistic, an interactive, and a constructive tool (Bana e Costa et al. 2003). It is a MCDA decision-aiding tool that evaluates options within multiple criteria. Its software called M-MACBETH requires input data provided by the decision-maker that is processed and calculated that generates meaningful output. The main difference between MACBETH and other MCDA techniques is that it requires only qualitative judgements about differences of attractiveness between two elements at a time to create numerical values (Baltazar et al. 2013). Besides the instruments mentioned in 2.3. the following ones regarding performance and efficiency analysis were also considered and studied initially: Data Envelopment Analysis (**DEA**), Free Disposal Hull (**FDH**), Total Factor Productivity (**TFP**), Surface Measure of Overall Performance (**SMOP**), Stochastic Frontier Analysis (**SFA**), and Supporting Platform for Airport Decision-making and Efficiency Analysis (**SPADE**).

4. IMPLEMENTATION OF THE RESEARCH QUESTION IN MACBETH

4.1. DECISION CONTEXT

The problem of Lisbon Airport and possible *NAL* alternative have been present in the agenda of several governments for nearly 60 years and have been marked by inconsistency and indecision that led to the postponement of the problem until today. The main objective of this analysis is to find the best location for *NAL*. While in this exemplificative research the sole key player and decision-maker is the researcher, in a real-life context it would involve central and local governments, the owner and operator of Lisbon Airport, local communities, experts, and others.

4.2. CANDIDATES AND CRITERIA SELECTION

From the 8 options considered for study: Alverca, Ota, Cascais, Sintra, Lisbon, Beja, Montijo, and Alcochete, the last 4 locations were chosen. Lisbon (Portela), Montijo, and Alcochete because they are the closest situated to Lisbon city centre. Montijo and Alcochete because they were studied by CIP (2007a) and LNEC (2008), and other organizations during the last 60 years. Beja because it was frequently supported by politicians (Lusa 2020) and discussed in newspapers (Cintra Torres 2020), and is population's preferred option, according to the survey carried out by INTERCAMPUS ("Beja Is The Preferred Solution" 2020). Options' scoring on Distance from Lisbon and on Closeness to protected areas such as Tagus and Sado Estuary Natural Reserves, Arrábida, Sintra-Cascais and Guadiana Valley Natural Parks, and others was based on distance in kilometres calculated by Google (n.d.). Scoring on Human resources and on Purchasing power was based on locations' NUTS II region labour force and purchasing power *per capita*, respectively, calculated by INE/PORDATA (2020), while scoring on Regional development was based on same regions' Human Development Index calculated by GDL (2020). Scoring on Orography was based on meters above sea level from topographic map drawn by OpenStreetMap (n.d.). Scoring on Seismology was based on seismic risk zones map drawn by IPMA (2018). Scoring on qualitative and on ranking criteria was based on previous studies and articles. For Beja location scores and judgements on Expansion potential, Infrastructure readiness, Exposure to noise, Flight safety, Transport systems, Hydrology, and Meteorology was based on study performed by EDAB (2004). For Alcochete location scores and judgements on same criteria was based on studies performed by CIP (2007a) and (2007b). For Montijo location scores and judgements on same criteria was based mainly on study performed by APA (2019), but also on study by CIP (2007a). For Lisbon location scores and judgements on same criteria (except Meteorology) was based on study performed by APA (2010), but also some insights were taken from EDAB (2004) and from ANA (2017). Lisbon's performance on Meteorology was based on comparative analysis with the 3 other options but also on Alcochete and Montijo's performance due to their geographical closeness. Even though these 16 criteria are mainly independent variables, options' scores on Total cost of implementation and on Net Present Value were based and dependent on a combination of other criteria. First criterion was based on combination of Infrastructure readiness and Transport systems, while second was based on combination of Total cost of implementation, Infrastructure readiness, Transport systems, and Regional development. Criteria weighting was based on swing weights technique where weights are decided based on the difference between the least and the most preferred option on each criterion. Criteria where difference between the best and the worst option is bigger have higher weight and more importance and criteria where that difference is smaller have lower weight and less importance.

4.2.1. OPTIONS

The criteria of sieving the options are closeness to Lisbon and level of their consideration during the last 60 years. As the new location will serve Lisbon Metropolitan Area, only existing airports and air bases located in the Lisbon District and its neighbouring Setúbal and Beja

Districts are considered. From the preliminary list that included Alverca Military Complex, Ota Military and Technical Training Center of the Air Force, Cascais Municipal Aerodrome, Sintra Air Base No. 1, **Lisbon** Airport, **Beja** Airport and Air Base No. 11 next to it, **Montijo** Air Base No. 6, and **Alcochete** Field Firing Range, the last **4 options** are chosen to be studied. These options are input into M-MACBETH (Fig. 6).

4.2.2. ASPECTS AND CRITERIA

Based on airport site selection criteria for the Yeongnam Region, in the UK, in Sydney, in Tokyo and Osaka (OECD/ITF 2017), and in previous studies of Lisbon (CIP 2007a and LNEC 2008) it is decided to assess the 4 options in **5 aspects** divided into **16 criteria** by building the value tree (Fig. 7 & 8). **Accessibility and readiness** aspect has 3 criteria. **Distance from Lisbon** is a quantitative criterion that calculates locations' distance in kilometres from Lisbon centre divided into 5 levels. (Fig. 9). **Transport systems** is a qualitative criterion that assesses available access modes, transport quality and price, and road quality and availability divided into 5 levels (Fig. 10). **Infrastructure readiness** is a qualitative criterion that assess existing facilities into 4 levels (Fig. 11). **Nature and environment** aspect has 5 criteria. **Closeness to protected areas** is a quantitative criterion that calculates locations' distance in kilometres from nearest protected area divided into 5 levels (Fig. 12). **Orography** is a qualitative criterion that calculates locations' hight in meters above sea level divided into 11 range levels (Fig. 13). **Meteorology** is a criterion that uses direct ranking of options consisting of 6 "non-criteria nodes" that evaluate weather conditions that includes temperature levels, atmospheric pressure, wind speed, humidity percentage, probability of precipitation, and level of cloudiness (Fig. 14). **Seismology** is a qualitative criterion that appraises locations' risks involved with their seismic zone divided into 6 levels (Fig. 15). **Hydrology** is a criterion that uses direct ranking of options that assesses probability of interference with nearly located drainage basins and underground water (Fig. 16). **Safety and sustainable development** aspect has 3 criteria. **Flight safety** is a qualitative criterion that evaluates flight proximity to inhabited areas divided into 3 levels (Fig. 17). **Exposure to noise** is a qualitative criterion that gauges how much noise disturbs residents in the vicinity divided into 5 levels (Fig. 18). **Expansion potential** is a qualitative criterion that assesses how much space of the surrounding area is available for expansion that will satisfy future demand divided into 4 levels (Fig. 19). **Economic factors** aspect has 3 criteria. **Human resources** is a quantitative criterion that calculates the quantity of available workforce in the region in thousands of individuals divided into 2 levels (Fig. 20). **Purchasing power** is a quantitative criterion that evaluates the probability and frequency of use of the new airport by the regional population based on purchasing power per capita divided into 3 levels (Fig. 21). **Regional development** is a quantitative criterion that calculates how much potential has the region affected by the airport to develop based on Human Development Index divided into 2 levels (Fig. 22). **Financial factors** aspect has 2 criteria. **Total cost of implementation** is a qualitative criterion that assesses what are the total construction/expansion costs divided into 4 levels (Fig. 23) This indicator is related to infrastructure readiness. **Net Present Value** is a criterion that uses direct ranking of options that shows which project is expected to be more profitable (Fig. 24). This indicator is related to regional development. All quantitative and qualitative criteria are based on a global scale of scoring where the end points are defined by the best and worst performance that can realistically occur (Barfod and Leleur 2014). Reference scores are set at 0 as lower reference and 100 as upper reference, and with global scales it means options can score below 0 points or above 100 points in certain criteria (Fig. 25).

4.3. SCORING

Scoring involves entering each option's performance into the model (Fig. 26) (Dodgson et al. 2009). In some cases, the options are ranked within the criterion. Next, differences of attractiveness between levels in quantitative or qualitative criteria, and between options in criteria with direct ranking of options are qualitatively judged by choosing whether there is no, very weak, weak, moderate, strong, v. strong, or extreme difference (Figs. 27 to 42). Differences of attractiveness are quantified by M-MACBETH to translate them into value scores in each criterion.

4.4. WEIGHTING

Weighting starts with setting weight references in each criterion, which was already done when defining the criteria (Fig. 43). Next, ranking of criteria weights is done by ranking their "overall references" from least important to most important and differences of overall attractiveness between overall references of each criterion are qualitatively judged by choosing whether there is no, very weak, weak, moderate, strong, v. strong, or extreme difference (Figs. 44 & 45). Differences of attractiveness are quantified by M-MACBETH to translate them into valuable weights.

4.5. RESULTS CALCULATION AND EXAMINATION

All these decisions and choices are combined and quantified by M-MACBETH to translate them into a table of overall scores and results. Figures 46 and 47 contain the overall results and detailed scores of each option in each criterion. These results show that the best location for the *NAL* is **Beja** location. With 27,99 points it is the option with highest overall score, followed by Lisbon with 19,89 points and by Alcochete with 18,20 points. Montijo location is the worst option with 17,99 points. In Distance from Lisbon, Lisbon is the best option with 95,24 points and Beja is the worst with -291,64 points. In Transport systems, Lisbon is the best option with 100 points and Beja is the worst with 0 points. In Infrastructure readiness, Beja and Lisbon are the best options with 100 points and Alcochete is the worst with -100 points. In Closeness to protected areas, Beja is the best option with 111,67 points and Alcochete is the worst with -100 points. In Orography, Montijo and Alcochete are the best options with 100 points and Beja and Lisbon are the worst with 91,30 points. In Meteorology, Beja is the best option with 100 points and the 3 other options are the worst with 0 points. In Seismology, Beja is the best option with 63,64 points and the 3 other options are the worst with 18,18 points. In Hydrology, Beja is the best option with 100 points and Alcochete is the worst with 0 points. In Flight safety, Beja and Alcochete are the best option with 100 points and Lisbon is the worst with 0 points. In Exposure to noise, Beja is the best option with 100 points and Lisbon is the worst with -300 points. In Expansion potential, Beja and Alcochete are the best options with 100 points and Lisbon is the worst option with 0 points. In Human Resources, Beja is the worst option with 12,82 points and the 3 other options are the best with 76,37 points. In Purchasing power, Beja is the worst option with 6,15 points and the 3 other options are the best with 100 points. In Regional development, Beja is the best option with 66,30 points and the 3 other options are the worst with 0 points. In Total cost of implementation, Lisbon is the best option with 100 points and Alcochete is the worst with 0 points. In Net Present Value, Beja is the best option with 100 points and Montijo is the worst with 0 points.

4.6. RESULTS ANALYSIS

Overall scores and results are then analysed through overall thermometer, option's profiles, differences profiles, and XY mapping (Figs. 48 to 59). To visualize how much overall scores and how preference choices may alter with changes in criteria weights a sensitivity analysis is performed to each criterion (Dodgson et al. 2009). To visualize how it would alter with varying quantities and degrees of imprecision and uncertainty of information a robustness analysis is performed. These two analyses allow to alienate some degree of subjectivity and add trustworthiness to the results.

4.6.1. OVERALL ANALYSIS

From the overall thermometer (Fig. 48) we can see that Beja is much better than the 3 other options that show similar scores. Options' small scores show that the four locations are not the most perfect alternatives. The criterion that contributes better to the Beja score is Closeness to protected areas and that contributes worse is Distance from Lisbon (Fig. 50). The criterion that contributes better to the Lisbon score is Distance from Lisbon and that contributes worse is Exposure to noise (Fig. 51). The criterion that contributes better to the Alcochete score is Flight safety and that contributes worse is Closeness to protected areas (Fig. 49). The criterion that contributes better to the Montijo score is Purchasing power and that contributes worse is Exposure to noise (Fig. 52). Beja is 8.10 points better than Lisbon (Fig. 55) and the criteria that create more difference between them is Exposure to noise, in favour of Beja, and Distance from Lisbon, in favour of Lisbon. Beja is 9.80 points better than Alcochete (Fig. 53) and the criteria that create more difference between them is Closeness to protected areas, in favour of Beja, and Distance from Lisbon, in favour of Alcochete. Beja is 10 points better than Montijo (Fig. 58) and the criteria that create more difference between them is Exposure to noise, in favour of Beja, and Distance from Lisbon, in favour of Montijo. Lisbon is 1.69 points better than Alcochete (Fig. 54) and the criteria that create more difference between them is Distance from Lisbon, in favour of Lisbon, and Exposure to noise, in favour of Alcochete. Lisbon is 1.90 points better than Montijo (Fig. 56) and the criteria that create more difference between them is Distance from Lisbon, in favour of Lisbon, and Exposure to noise, in favour of Montijo. Alcochete is 0.20 points better than Montijo (Fig. 57) and the criteria that create more difference between them is Exposure to noise, in favour of Alcochete, and Closeness to protected areas, in favour of Montijo.

4.6.2. SENSITIVITY ANALYSIS

Performing sensitivity analysis is intended to understand how much changes in criteria weights could alter the overall scores and the preferred option (Dodgson et al. 2009). With any changes in Infrastructure readiness, Meteorology, Seismology, Hydrology, Expansion potential, Regional development, or Net Present Value weights, either increase or decrease, Beja would anyway remain the preferred option. Huge increase in either Closeness to protected areas, Flight safety, or Exposure to noise weights would mean Beja remains the preferred option. Huge increase in either Orography, Flight safety, Expansion potential, Human resources, or Purchasing power weights would mean Alcochete is the preferred option. Huge increase in either Distance from Lisbon, Transport systems, Infrastructure readiness, Human resources, Purchasing power, or Total cost of implementation weights would mean Lisbon is the preferred option. Huge increase in either Orography, Human resources, or Purchasing power weights would mean Montijo is the preferred option. Huge decrease in either Distance from Lisbon, Transport systems, Orography, Human resources, Purchasing power, or Total cost of implementation weights would mean Beja remains the preferred option. Huge decrease in either Infrastructure readiness or Closeness to protected areas weights would mean Alcochete is the preferred option. Huge decrease in either Flight safety or Exposure to noise weights would mean Lisbon is the preferred option. Montijo would not be the preferred option in any case of weight decrease. Figures 60 to 75 show in detail sensitivity analysis for all the 16 criteria.

4.6.3. ROBUSTNESS ANALYSIS

Performing robustness analysis is intended to understand how changes in degrees of information imprecision, uncertainty, and completeness could alter the overall scores and the preferred option. First of all, it should be explained that ordinal information is related only to rank, MACBETH information is related to the semantic judgements entered into the model, cardinal information is related to the specific scale validated by the decision maker, local information refers to specific information about a particular criterion, and global information refers to information about weights. First analysis is on varying amounts of information. It is not sure without the cardinal global information what option is the best (Fig. 76). However, including it makes obvious that Beja dominates other options (Fig. 77). Second analysis is on varying degrees of cardinal information imprecision. With 10% of imprecision about Distance from Lisbon and 0% about the remaining criteria the best option changes from Beja to Lisbon (Fig. 78). With 99% of imprecision about all other criteria individually and 0% about the remaining the best option remains Beja, despite changes of preference and dominance in the 3 other options (Figs. 79 to 90). Third analysis is on options' performance imprecision. With imprecision about Lisbon's performance on Infrastructure readiness (Great or Good) and Alcochete's performance on Flight safety (Safe or Unsettling), the only change is that Alcochete no more dominates Montijo (Fig. 91).

5. FINAL DECISION, CONCLUSIONS AND RECOMMENDATIONS

The background of the studied problem has showed that the *NAL* project was constantly postponed mainly due to its decision process complexity (Gonçalves and Marreiros 2014). This research has concluded that the best option is Beja. Anyway, the four options' relatively small overall scores mean these alternatives and other locations considered previously are far from optimal solutions to the Lisbon Airport problem. Hence, a larger set of options should be screened out. A MCDA type of approach is preferential to this problem as it is a straightforward methodology based on qualitative judgements that shows in detail the pros and cons of each option in each criterion. On the other hand, it involves certain degrees of subjectivity, which means it should include as much expert involvement as possible to generate different points of view. An airport is a complex infrastructure, and its construction will always involve trade-offs between economic benefits and environmental aspects (OECD/ITF 2017). Each side of the consequences should be studied in detail to make a decision about what is more beneficial to some and what is less harmful for others. Airport site selection process should preferentially include a cost-benefit analysis to understand each option's socioeconomic benefit to society and a multi-criteria analysis to understand who could be most benefited and who could be most harmed. An important aspect of airport site selection process is the analysis methodology. A robust and trustworthy analysis of options should always be performed in a comparative manner.

6. LIMITATIONS

This research and the information processed in it may be subject to certain limitations. All judgements, appraisals, assessments, choices, and decisions were made by only one participant: the researcher. It means all outcomes could be the result of some sort of cognitive bias, such as representativeness or availability heuristic (Dodgson et al. 2009), and researcher's own perception of the situation. Representativeness heuristic because some judgements could have been based on perceptions about what is good performance and what is bad performance. Availability heuristic because judgements could have been based on a small available portion of information. Better information might not have been accessible. Even though MCDA methodology and MACBETH technique are solid instruments that allow a robust analysis that could overcome those limitations, some sort of subjectivity could be present in this research, which is natural in a typical MCDA decision process. But the main objective of this research is applying the MCDA approach to the NAL problem in an exemplificative way. In a real-life context the research would require more robustness and the participation of different decision makers, stakeholders, experts, and other key players. While scoring on quantitative criteria used to analyse the options was based on more exact data, scoring on criteria that used direct ranking of options and on qualitative criteria was based on subjective judgement about conclusions taken from studies and papers which could also involve subjectivity. While the criteria weighting was reasoned by using a frequently-used technique - swing weighting, a more accurate analysis could also involve the use of voting system, where a voting committee formed by key players could make a fairer decision. Other alternatives include giving equal weight to critical decision factors or performing sensitivity analysis (OECD/ITF 2017).

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APPENDICES

1969	1982	1990	1994	1998/1999		
GNAL	ANA	ANA	ANA	EPIA's	Aéroports de Paris	Decisão final
Alcochete						
Fonte da Telha	Fonte da Telha					
Montijo	Montijo		Montijo A Montijo B			
Porto Alto	Porto Alto					
Rio Frio	Rio Frio	Rio Frio	Rio Frio	Rio Frio 08/26 Rio Frio 17/35	Rio Frio 08/26 Rio Frio 17/35	
	Alverca					
	Azambuja					
	Granja					
	Marateca					
	Ota	Ota	Ota	Ota	Ota	Ota
	Portela					
	Santa Cruz					
	Tires					

Fig. 1 – Alternatives locations of the New Lisbon Airport studied between 1969 and 1999 (Source: Confederação da Indústria Portuguesa)

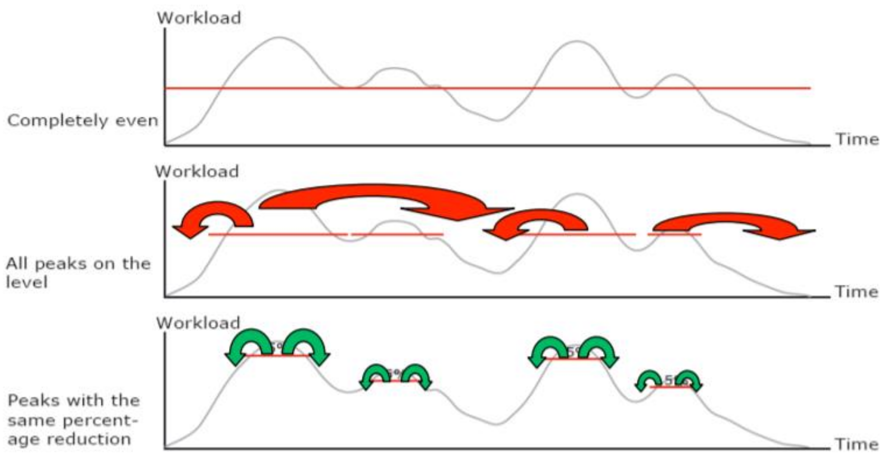


Fig. 2 – De-peaking strategies (Source: Luethi, Kisseleff and Nash)

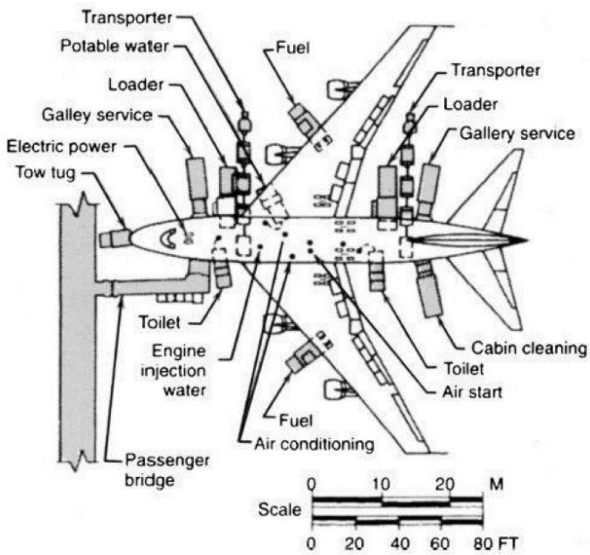


Fig. 3 – Ground handling layout (Source: Boeing Airline Company)

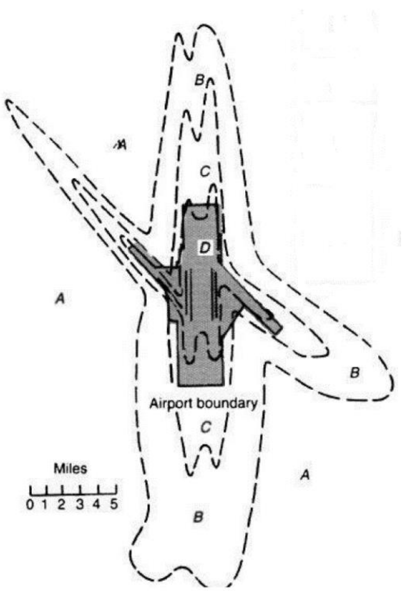


Fig. 4 – Airport noise contour map (Source: FAA)

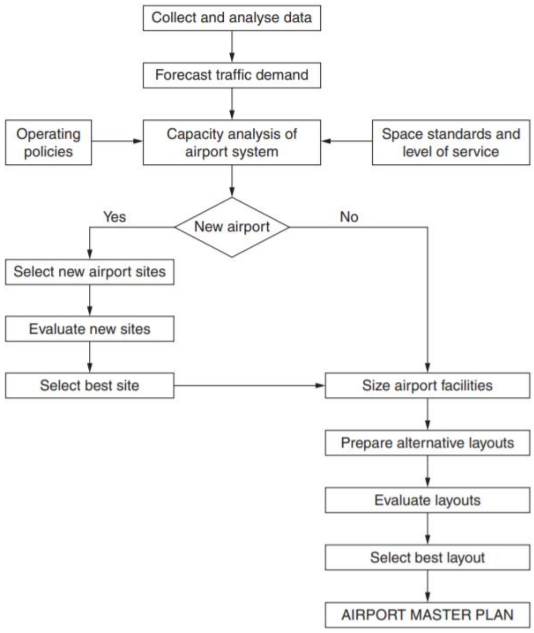
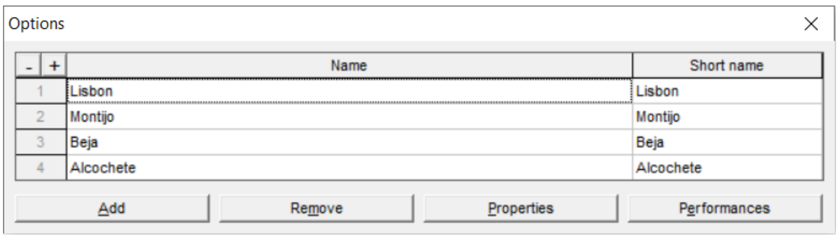


Fig. 5 – Airport master plan steps flowchart (Source: Horonjeff et al.)



- +	Name	Short name
1	Lisbon	Lisbon
2	Montijo	Montijo
3	Beja	Beja
4	Alcochete	Alcochete

Fig. 6 – Location options studied

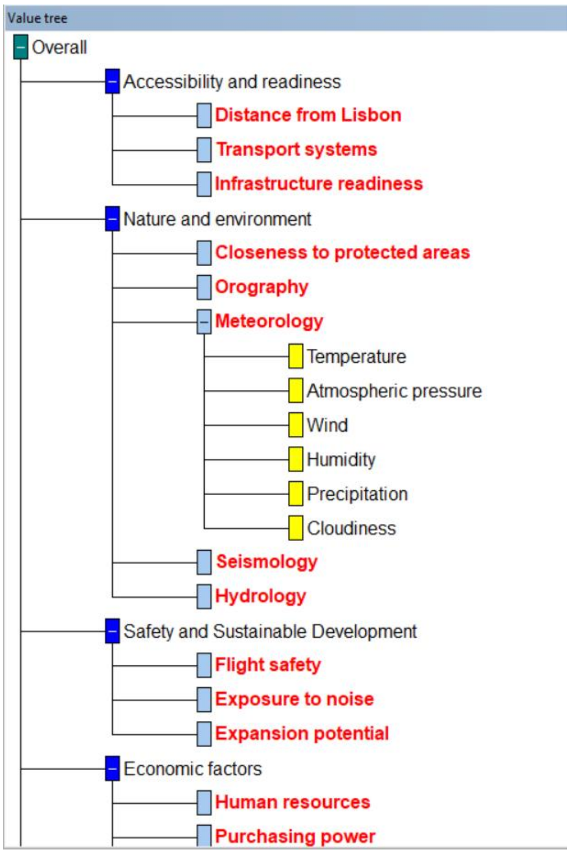


Fig. 7 – Value tree of criteria – part 1

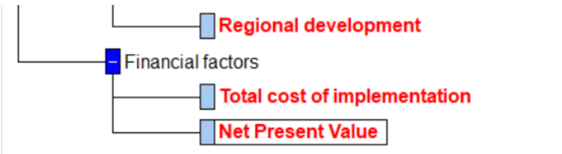


Fig. 8 – Value tree of criteria – part 2

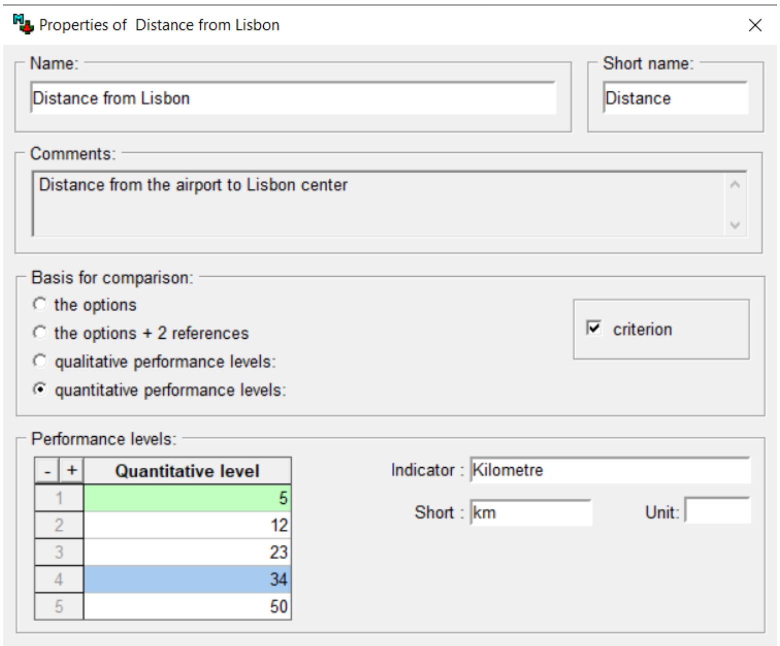


Fig. 9 – Properties of Distance from Lisbon criterion

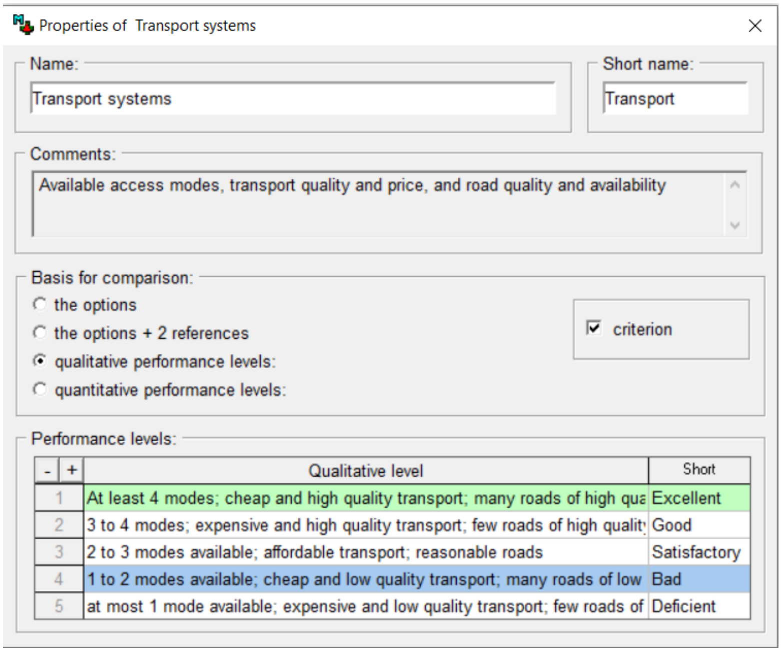


Fig. 10 – Properties of Transport systems criterion

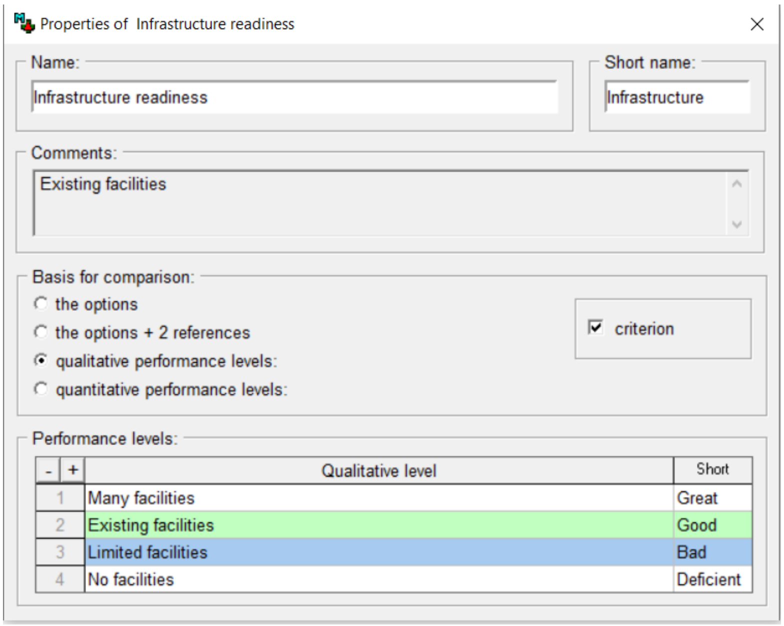


Fig. 11 – Properties of Infrastructure readiness criterion

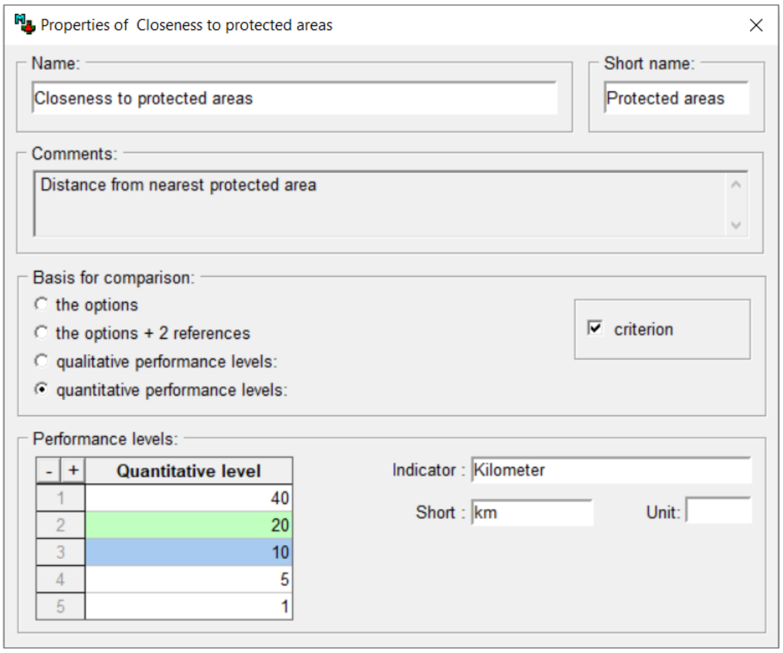


Fig. 12 – Properties of Closeness to protected areas criterion

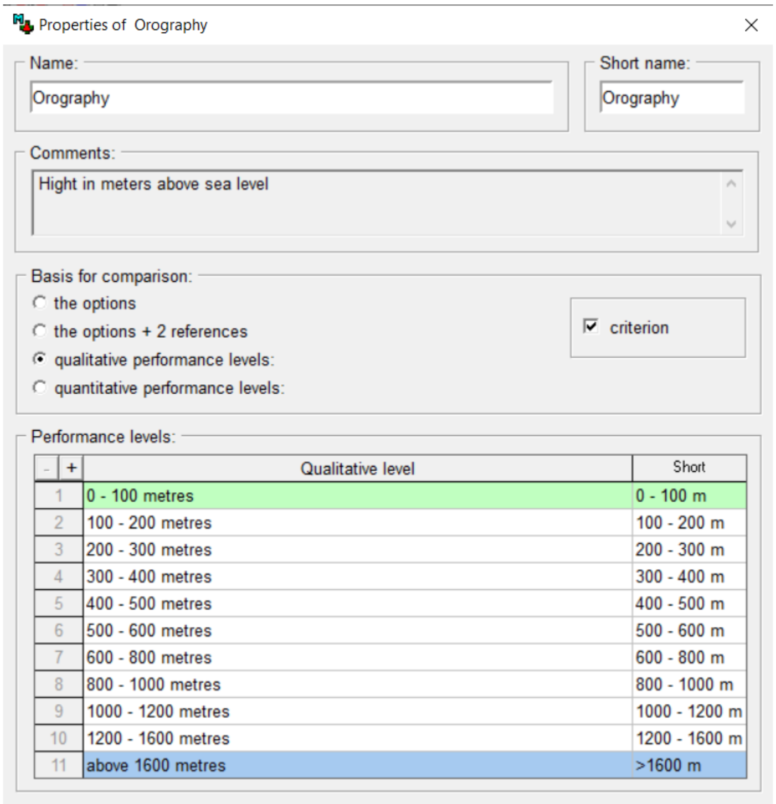


Fig. 13 – Properties of Orography criterion

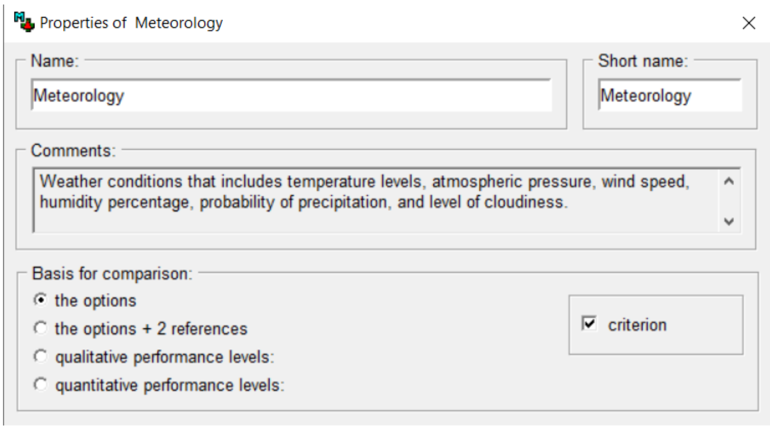


Fig. 14 – Properties of Meteorology criterion

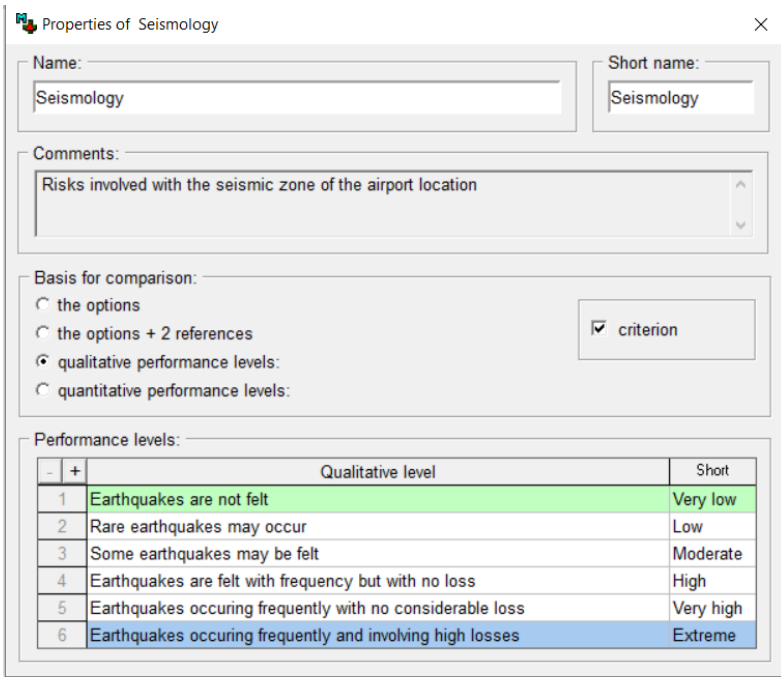


Fig. 15 – Properties of Seismology criterion

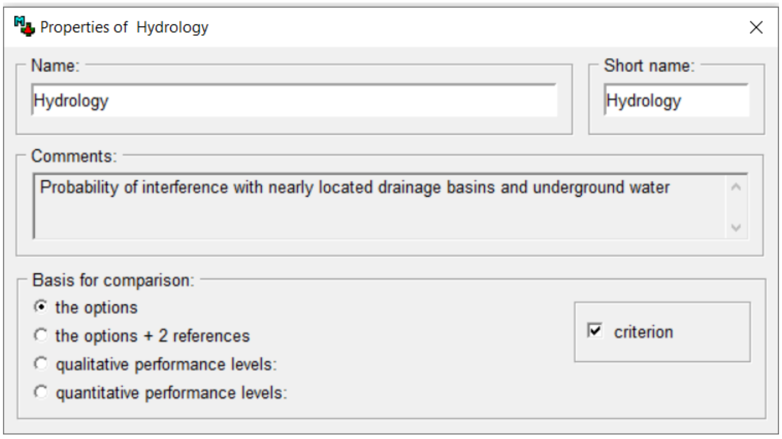


Fig. 16 – Properties of Hydrology criterion

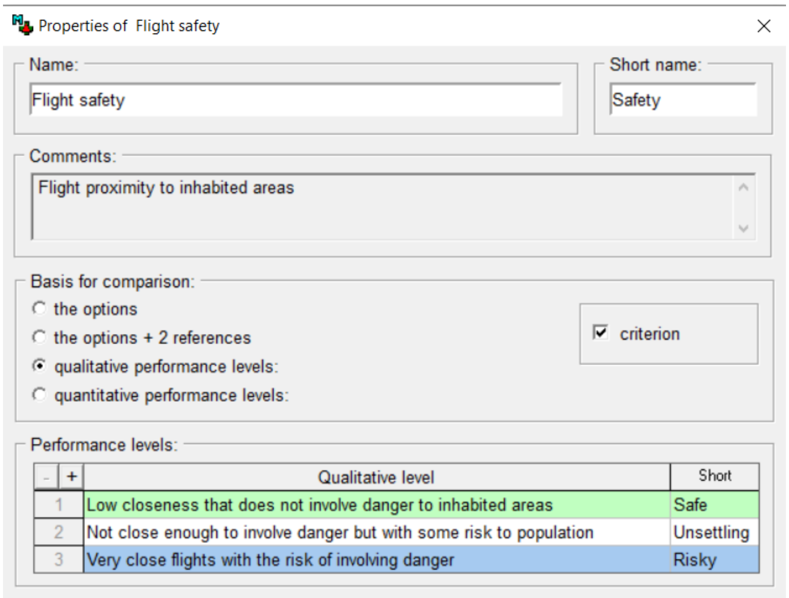


Fig. 17 – Properties of Flight safety criterion

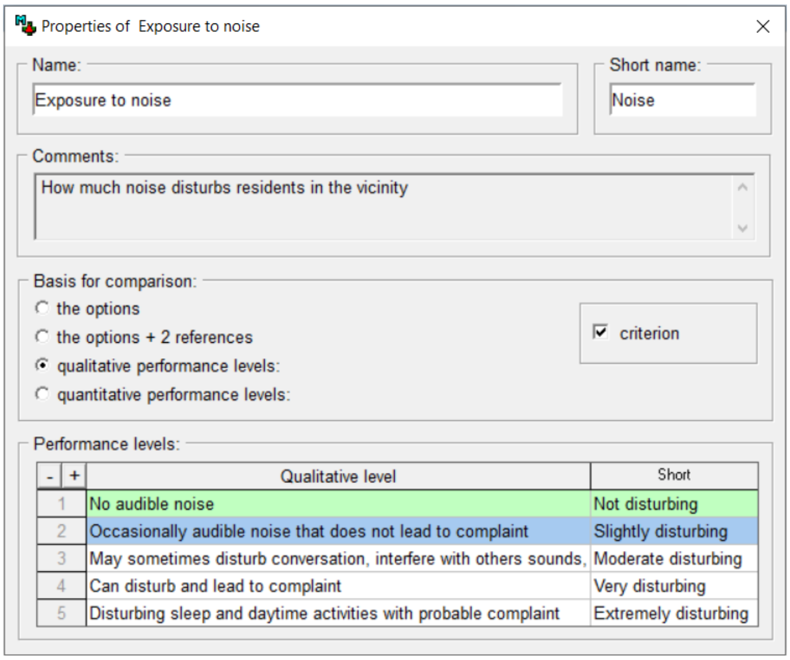


Fig. 18 – Properties of Exposure to noise criterion

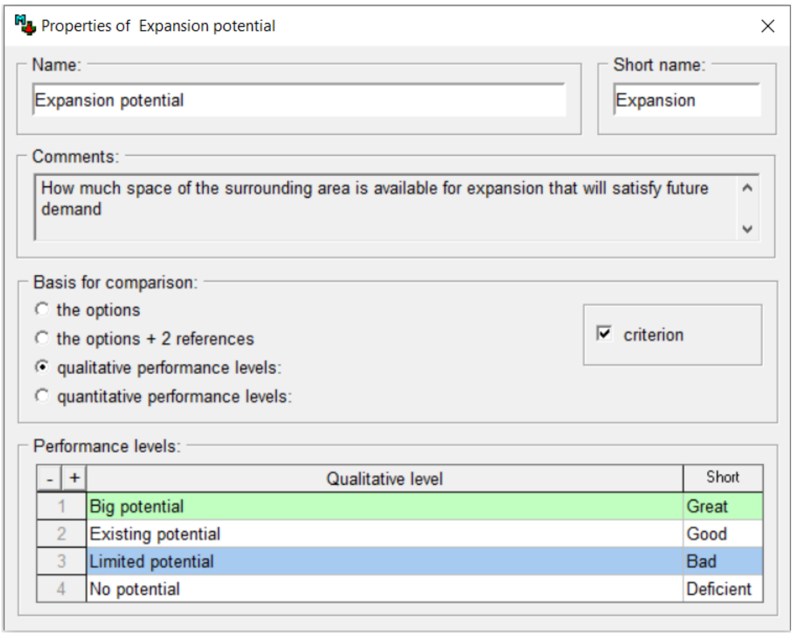


Fig. 19 – Properties of Expansion potential criterion

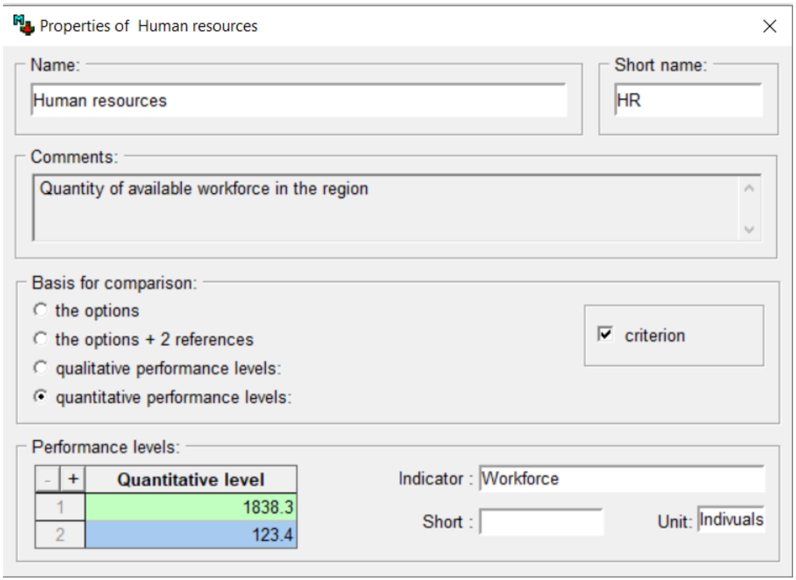


Fig. 20 – Properties of Human resources criterion

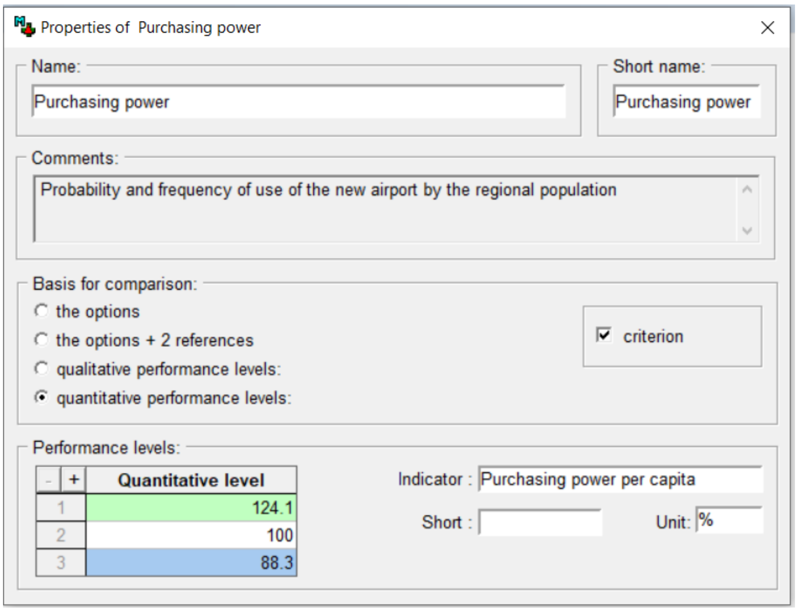


Fig. 21 – Properties of Purchasing power criterion

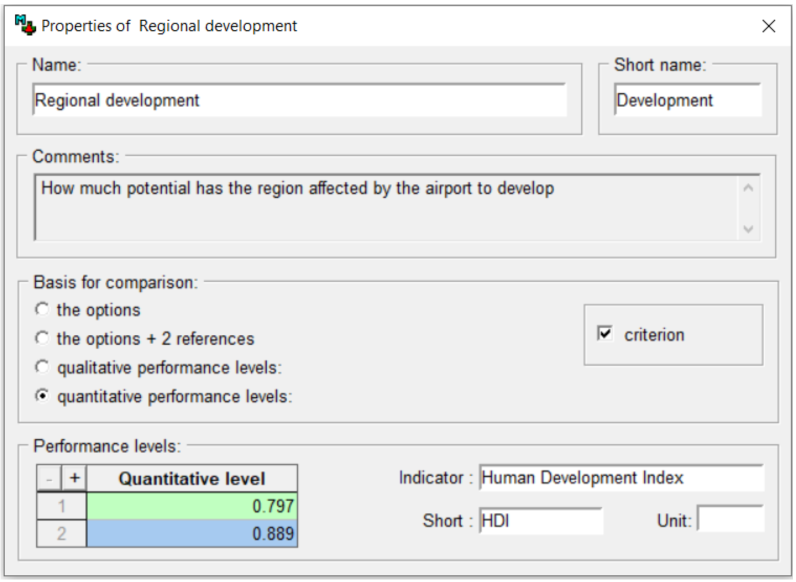


Fig. 22 – Properties of Regional development criterion

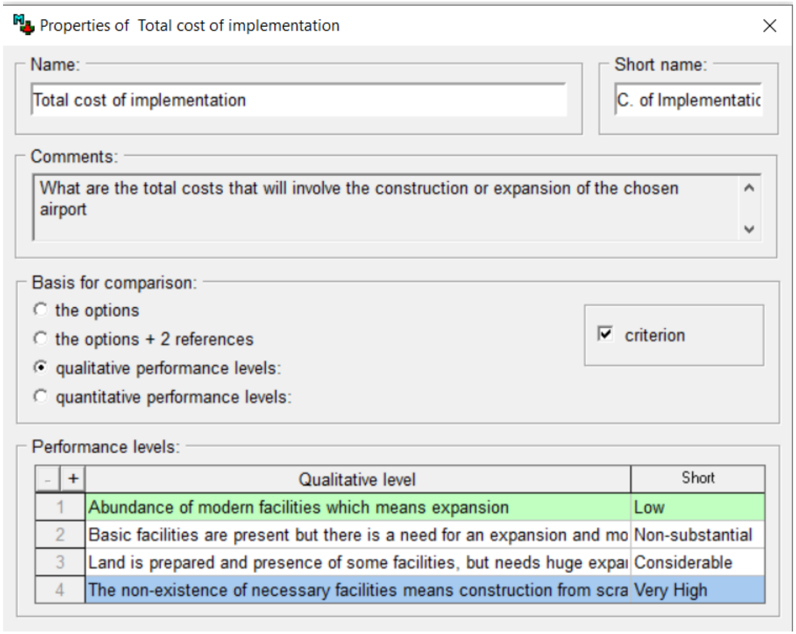


Fig. 23 – Properties of Total cost of implementation criterion

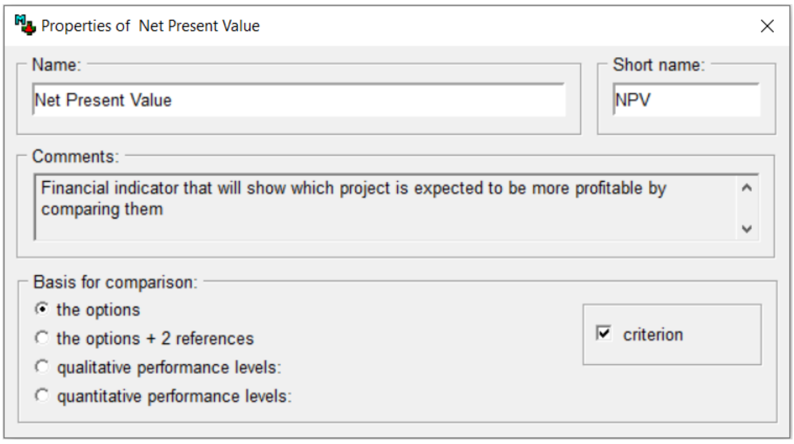


Fig. 24 – Properties of Net Present Value criterion

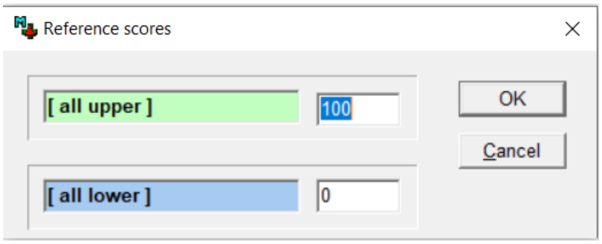


Fig. 25 – Upper and lower reference scores

Table of performances

Options	Distance	Transport	Infrastructure	Protected areas	Orography	Seismology	Safety	Noise	Expansion	HR	Purchasing power	Development	C. of Implementation
Lisbon	6	Excellent	± Good	5	100 - 200 m	Very high	Risky	Very disturbing	Bad	1433	124.1	0.889	Low
Montijo	37	Good	Bad	10	0 - 100 m	Very high	Unsettling	Moderate disturbing	Good	1433	124.1	0.889	Considerable
Beja	174	Bad	Good	27	100 - 200 m	Moderate	Safe	Not disturbing	Great	343.3	90.1	0.828	Non-substantial
Alcochete	36	Good	Deficient	1	0 - 100 m	Very high	± Safe	Slightly disturbing	Great	1433	124.1	0.889	Very high

Fig. 26 – Options' performance in each criterion

Distance from Lisbon

	5	12	23	34	50	Current scale
5	no	weak	moderate	strong	v. strong	100.00
12		no	weak	moderate	strong	66.67
23			no	weak	moderate	33.33
34				no	weak-mod	0.00
50					no	-33.33

extreme / v. strong / strong / moderate / weak / very weak / no

Consistent judgements

Fig. 27 – Differences of attractiveness judgements of Distance from Lisbon criterion

Transport systems

	Excellent	Good	Satisfactory	Bad	Deficient	Current scale
Excellent	no	vweak-weak	weak-mod	strong	v. strong	100.00
Good		no	weak-mod	strong	v. strong	83.33
Satisfactory			no	moderate	strong	50.00
Bad				no	vweak-weak	0.00
Deficient					no	-33.33

extreme / v. strong / strong / moderate / weak / very weak / no

Consistent judgements

Fig. 28 – Differences of attractiveness judgements of Transport systems criterion

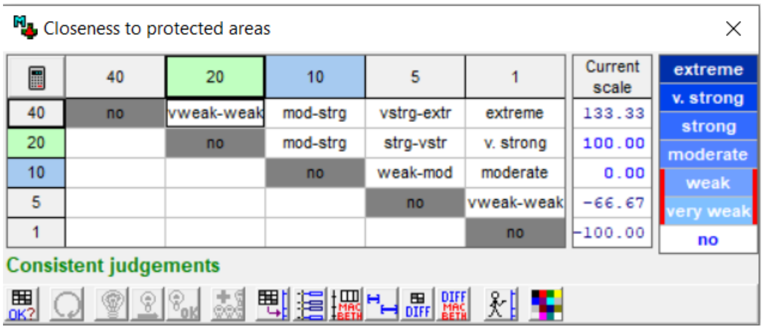
Infrastructure readiness

	Great	Good	Bad	Deficient	Current scale
Great	no	very weak	weak	moderate	200.00
Good		no	very weak	weak	100.00
Bad			no	very weak	0.00
Deficient				no	-100.04

extreme / v. strong / strong / moderate / weak / very weak / no

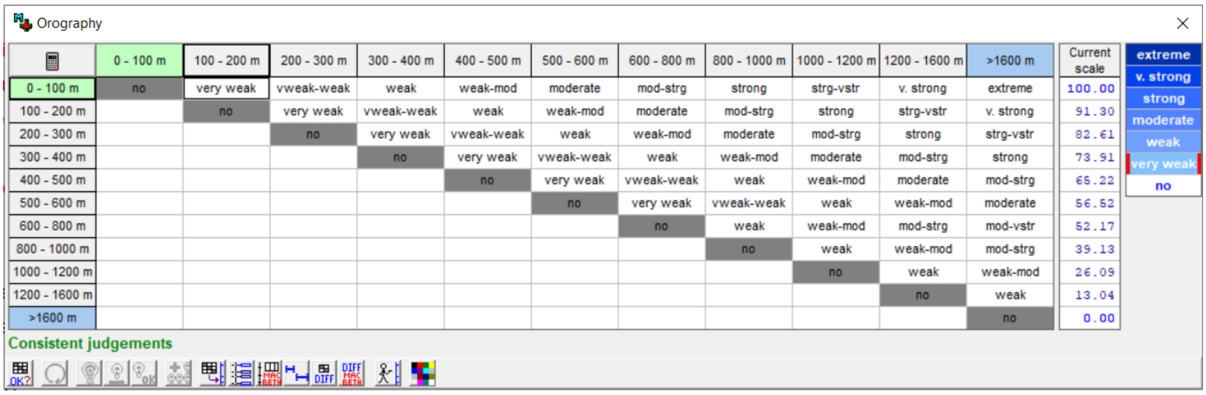
Consistent judgements

Fig. 29 – Differences of attractiveness judgements of Infrastructure readiness criterion



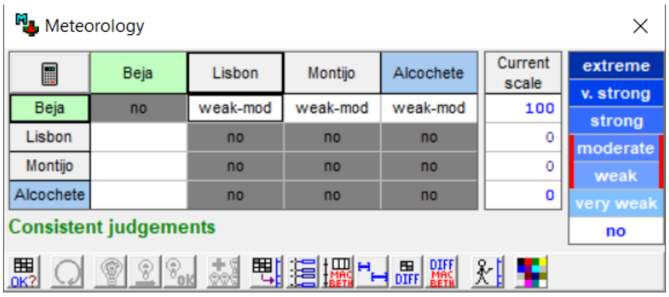
	40	20	10	5	1	Current scale
40	no	vweak-weak	mod-strg	vstrg-extr	extreme	133.33
20		no	mod-strg	strg-vstr	v. strong	100.00
10			no	weak-mod	moderate	0.00
5				no	vweak-weak	-66.67
1					no	-100.00

Fig. 30 – Differences of attractiveness judgements of Closeness to protected areas criterion



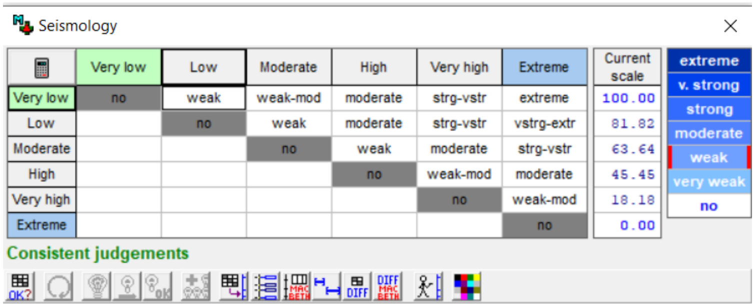
	0 - 100 m	100 - 200 m	200 - 300 m	300 - 400 m	400 - 500 m	500 - 600 m	600 - 800 m	800 - 1000 m	1000 - 1200 m	1200 - 1600 m	>1600 m	Current scale
0 - 100 m	no	very weak	vweak-weak	weak	weak-mod	moderate	mod-strg	strong	strg-vstr	v. strong	extreme	100.00
100 - 200 m		no	very weak	vweak-weak	weak	weak-mod	moderate	mod-strg	strong	strg-vstr	v. strong	91.30
200 - 300 m			no	very weak	vweak-weak	weak	weak-mod	moderate	mod-strg	strong	strg-vstr	82.61
300 - 400 m				no	very weak	vweak-weak	weak	weak-mod	moderate	mod-strg	strong	73.91
400 - 500 m					no	very weak	vweak-weak	weak	weak-mod	moderate	mod-strg	65.22
500 - 600 m						no	very weak	vweak-weak	weak	weak-mod	moderate	56.52
600 - 800 m							no	weak	weak-mod	mod-strg	mod-vstr	52.17
800 - 1000 m								no	weak	weak-mod	mod-strg	39.13
1000 - 1200 m									no	weak	weak-mod	26.09
1200 - 1600 m										no	weak	13.04
>1600 m											no	0.00

Fig. 31 – Differences of attractiveness judgements of Orography criterion



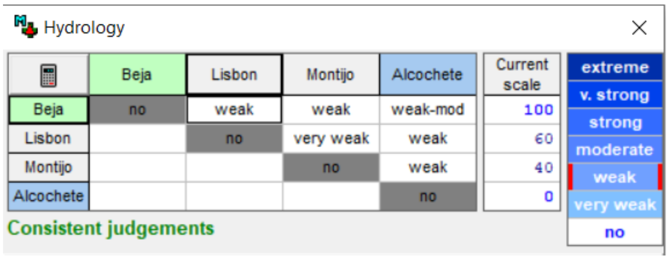
	Beja	Lisbon	Montijo	Alcochete	Current scale
Beja	no	weak-mod	weak-mod	weak-mod	100
Lisbon		no	no	no	0
Montijo		no	no	no	0
Alcochete		no	no	no	0

Fig. 32 – Differences of attractiveness judgements of Meteorology criterion



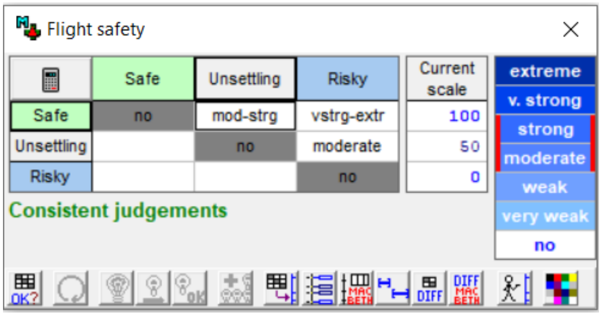
	Very low	Low	Moderate	High	Very high	Extreme	Current scale
Very low	no	weak	weak-mod	moderate	strg-vstr	extreme	100.00
Low		no	weak	moderate	strg-vstr	vstrg-extr	81.82
Moderate			no	weak	moderate	strg-vstr	63.64
High				no	weak-mod	moderate	45.45
Very high					no	weak-mod	18.18
Extreme						no	0.00

Fig. 33 – Differences of attractiveness judgements of Seismology criterion



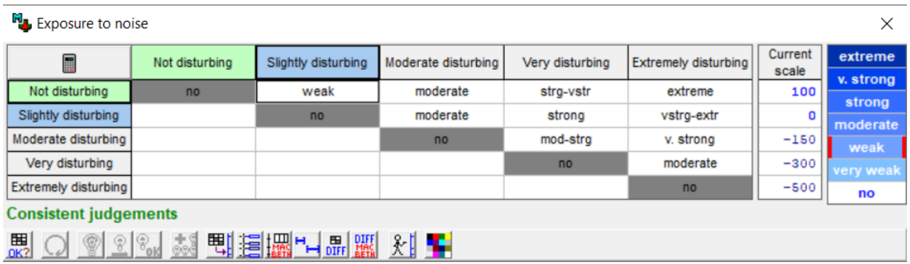
	Beja	Lisbon	Montijo	Alcochete	Current scale
Beja	no	weak	weak	weak-mod	100
Lisbon		no	very weak	weak	60
Montijo			no	weak	40
Alcochete				no	0

Fig. 34 – Differences of attractiveness judgements of Hydrology criterion



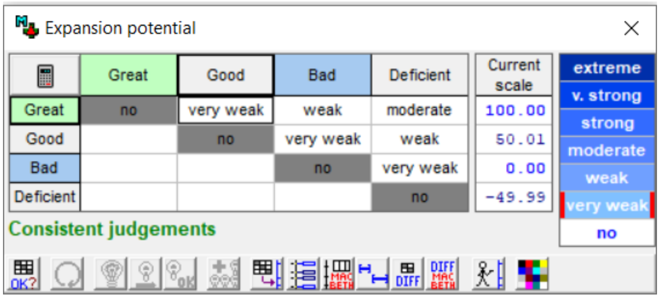
	Safe	Unsettling	Risky	Current scale
Safe	no	mod-strg	vstrg-extr	100
Unsettling		no	moderate	50
Risky			no	0

Fig. 35 – Differences of attractiveness judgements of Flight safety criterion



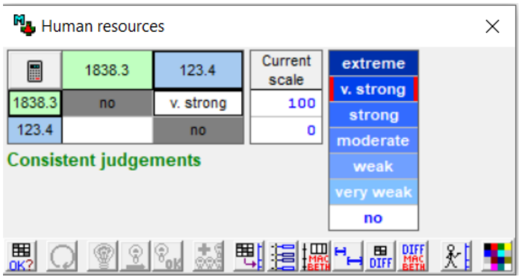
	Not disturbing	Slightly disturbing	Moderate disturbing	Very disturbing	Extremely disturbing	Current scale
Not disturbing	no	weak	moderate	strg-vstr	extreme	100
Slightly disturbing		no	moderate	strong	vstrg-extr	0
Moderate disturbing			no	mod-strg	v. strong	-150
Very disturbing				no	moderate	-300
Extremely disturbing					no	-500

Fig. 36 – Differences of attractiveness judgements of Exposure to noise criterion



	Great	Good	Bad	Deficient	Current scale
Great	no	very weak	weak	moderate	100.00
Good		no	very weak	weak	50.01
Bad			no	very weak	0.00
Deficient				no	-49.99

Fig. 37 – Differences of attractiveness judgements of Expansion potential criterion



	1838.3	123.4	Current scale
1838.3	no	v. strong	100
123.4		no	0

Fig. 38 – Differences of attractiveness judgements of Human resources criterion

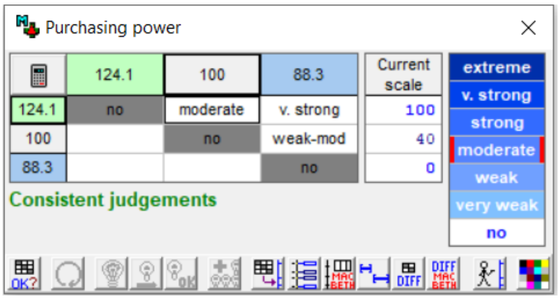


Fig. 39 – Differences of attractiveness judgements of Purchasing power criterion

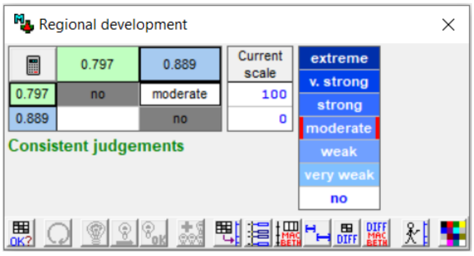


Fig. 40 – Differences of attractiveness judgements of Regional development criterion

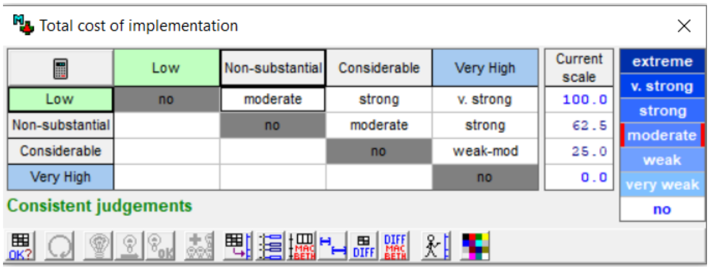


Fig. 41 – Differences of attractiveness judgements of Total cost of implementation criterion

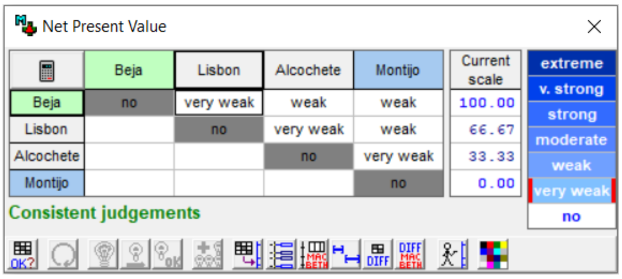


Fig. 42 – Differences of attractiveness judgements of Net Present Value criterion

Weighting references

references overall
[Distance]
[Protected areas]
[Safety]
[C. of Implementation]
[Noise]
[Purchasing power]
[Transport]
[Infrastructure]
[Seismology]
[HR]
[Hydrology]
[Meteorology]
[Expansion]
[Development]
[NPV]
[Orography]
[all lower]

Distance	Transport	Infrastructure	Protected areas	Orography	Meteorology	Seismology	Hydrology	Safety	Noise	Expansion	HR	Purchasing power	Development	C. of Implementation	NPV
5	Excellent	Great	40	0 - 100 m	Beja	Very low	Beja	Safe	Not disturbing	Great	1838.3	124.1	0.797	Low	Beja
12	Good	Good	20	100 - 200 m	Lisbon	Low	Lisbon	Unsettling	Slightly disturbing	Good	123.4	100	0.889	Non-substantial	Lisbon
23	Satisfactory	Bad	10	200 - 300 m	Montijo	Moderate	Montijo	Risky	Moderate disturbing	Bad		88.3		Considerable	Alcochete
34	Bad	Deficient	5	300 - 400 m	Alcochete	High	Alcochete		Very disturbing	Deficient				Very high	Montijo
50	Deficient		1	400 - 500 m		Very high			Extremely disturbing						
				500 - 600 m		Extreme									
				600 - 800 m											
				800 - 1000 m											
				1000 - 1200 m											
				1200 - 1600 m											
				> 1600 m											

Fig. 43 – Criteria weighting references

	[Distance]	[Protected areas]	[Safety]	[C. of Implementation]	[Noise]	[Purchasing power]	[Transport]	[Infrastructure]	[Seismology]	[HR]	[Hydrology]	Current scale
[Distance]	no	very weak	very weak	very weak	vweak-weak	vweak-weak	weak	moderate	moderate	moderate	mod-strg	100.00
[Protected areas]		no	no	very weak	very weak	very weak	vweak-weak	weak-mod	weak-mod	weak-mod	moderate	89.99
[Safety]		no	no	very weak	very weak	very weak	vweak-weak	weak-mod	weak-mod	weak-mod	moderate	89.99
[C. of Implementation]				no	very weak	very weak	very weak	weak	weak	weak	weak-mod	80.07
[Noise]					no	no	very weak	vweak-weak	vweak-weak	vweak-weak	weak	69.97
[Purchasing power]					no	no	very weak	vweak-weak	vweak-weak	vweak-weak	weak	69.97
[Transport]							no	very weak	very weak	very weak	vweak-weak	60.05
[Infrastructure]								no	no	no	very weak	45.04
[Seismology]								no	no	no	very weak	45.04
[HR]								no	no	no	very weak	45.04
[Hydrology]											no	32.53
[Meteorology]											no	32.53
[Expansion]												21.27
[Development]												21.27
[NPV]												21.27
[Orography]												10.01
[all lower]												0.00

extreme
v. strong
strong
moderate
weak
very weak
no

Fig. 44 – Criteria's weights overall references ranking and differences of attractiveness judgements of criteria's weights overall references – part 1

	[Transport]	[Infrastructure]	[Seismology]	[HR]	[Hydrology]	[Meteorology]	[Expansion]	[Development]	[NPV]	[Orography]	[all lower]	Current scale
[Distance]	weak	moderate	moderate	moderate	mod-strg	mod-strg	strong	strong	strong	strong	positive	100.00
[Protected areas]	vweak-weak	weak-mod	weak-mod	weak-mod	moderate	moderate	mod-strg	mod-strg	mod-strg	strg-vstr	positive	89.99
[Safety]	vweak-weak	weak-mod	weak-mod	weak-mod	moderate	moderate	mod-strg	mod-strg	mod-strg	strg-vstr	positive	89.99
[C. of Implementation]	very weak	weak	weak	weak	weak-mod	weak-mod	moderate	moderate	moderate	strong	positive	80.07
[Noise]	very weak	vweak-weak	vweak-weak	vweak-weak	weak	weak	weak-mod	weak-mod	weak-mod	mod-strg	positive	69.97
[Purchasing power]	very weak	vweak-weak	vweak-weak	vweak-weak	weak	weak	weak-mod	weak-mod	weak-mod	mod-strg	positive	69.97
[Transport]	no	very weak	very weak	very weak	vweak-weak	vweak-weak	weak	weak	weak	moderate	positive	60.05
[Infrastructure]		no	no	no	very weak	very weak	very weak	very weak	very weak	weak	positive	45.04
[Seismology]		no	no	no	very weak	very weak	very weak	very weak	very weak	weak	positive	45.04
[HR]		no	no	no	very weak	very weak	very weak	very weak	very weak	weak	positive	45.04
[Hydrology]					no	no	very weak	very weak	very weak	vweak-weak	positive	32.53
[Meteorology]					no	no	very weak	very weak	very weak	vweak-weak	positive	32.53
[Expansion]							no	no	no	very weak	positive	21.27
[Development]							no	no	no	very weak	positive	21.27
[NPV]							no	no	no	very weak	positive	21.27
[Orography]										no	positive	10.01
[all lower]											no	0.00

extreme
v. strong
strong
moderate
weak
very weak
no

Fig. 45 - Criteria's weights overall references ranking and differences of attractiveness judgements of criteria's weights overall references – part 2

Table of scores

Options	Overall	Distance	Transport	Infrastructure	Protected areas	Orography	Meteorology	Seismology	Hydrology	Safety	Noise	Expansion	HR	Purchasing power
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Beja	27.99	-291.64	0.00	100.00	111.67	91.30	100.00	63.64	100.00	100.00	100.00	100.00	12.82	6.15
Lisbon	19.89	95.24	100.00	100.00	-66.67	91.30	0.00	18.18	60.00	0.00	-300.00	0.00	76.37	100.00
Alcochete	18.20	-4.17	83.33	-100.00	-100.00	100.00	0.00	18.18	0.00	100.00	0.00	100.00	76.37	100.00
Montijo	17.99	-6.25	83.33	0.00	0.00	100.00	0.00	18.18	40.00	50.00	-150.00	50.00	76.37	100.00
[all lower]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.1199	0.0720	0.0540	0.1079	0.0120	0.0390	0.0540	0.0390	0.1079	0.0839	0.0255	0.0540	0.0839

Fig. 46 – Options’ overall scores and detailed scores in each criterion – part 1

Table of scores

Options	Overall	Protected areas	Orography	Meteorology	Seismology	Hydrology	Safety	Noise	Expansion	HR	Purchasing power	Development	C. of Implementation	NPV
[all upper]	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Beja	27.99	111.67	91.30	100.00	63.64	100.00	100.00	100.00	100.00	12.82	6.15	66.30	62.50	100.00
Lisbon	19.89	-66.67	91.30	0.00	18.18	60.00	0.00	-300.00	0.00	76.37	100.00	0.00	100.00	66.67
Alcochete	18.20	-100.00	100.00	0.00	18.18	0.00	100.00	0.00	100.00	76.37	100.00	0.00	0.00	33.33
Montijo	17.99	0.00	100.00	0.00	18.18	40.00	50.00	-150.00	50.00	76.37	100.00	0.00	25.00	0.00
[all lower]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Weights :		0.1079	0.0120	0.0390	0.0540	0.0390	0.1079	0.0839	0.0255	0.0540	0.0839	0.0255	0.0960	0.0255

Fig. 47 - Options’ overall scores and detailed scores in each criterion – part 2

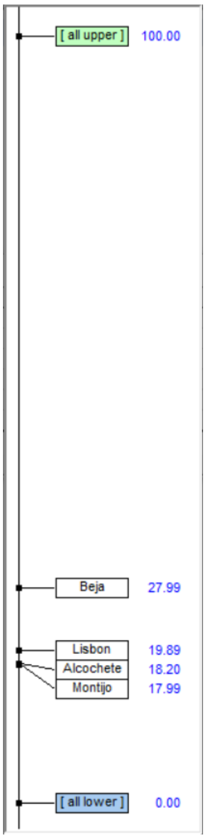


Fig. 48 – Overall thermometer with options’ scores

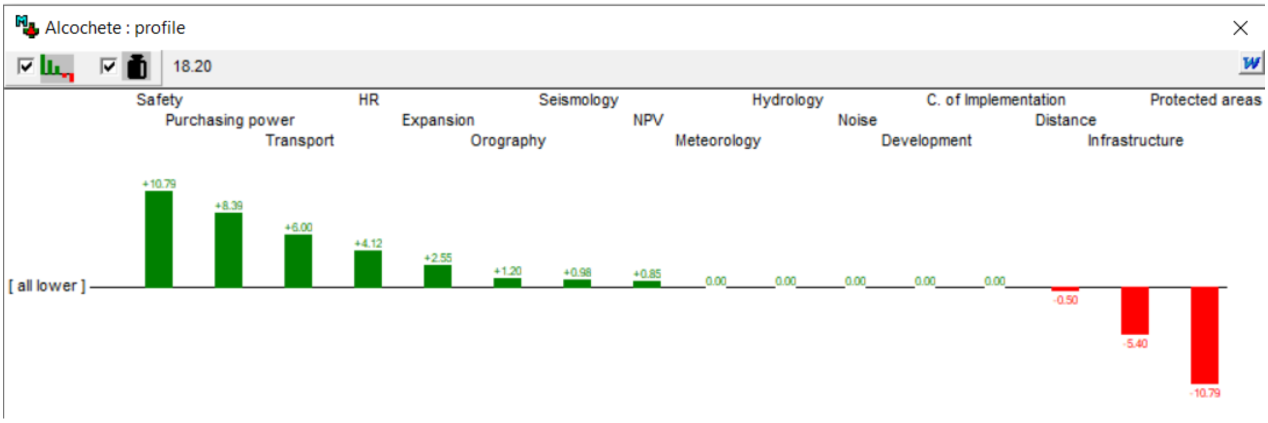


Fig. 49 – Alcochete weighted scores profile with ordered bars

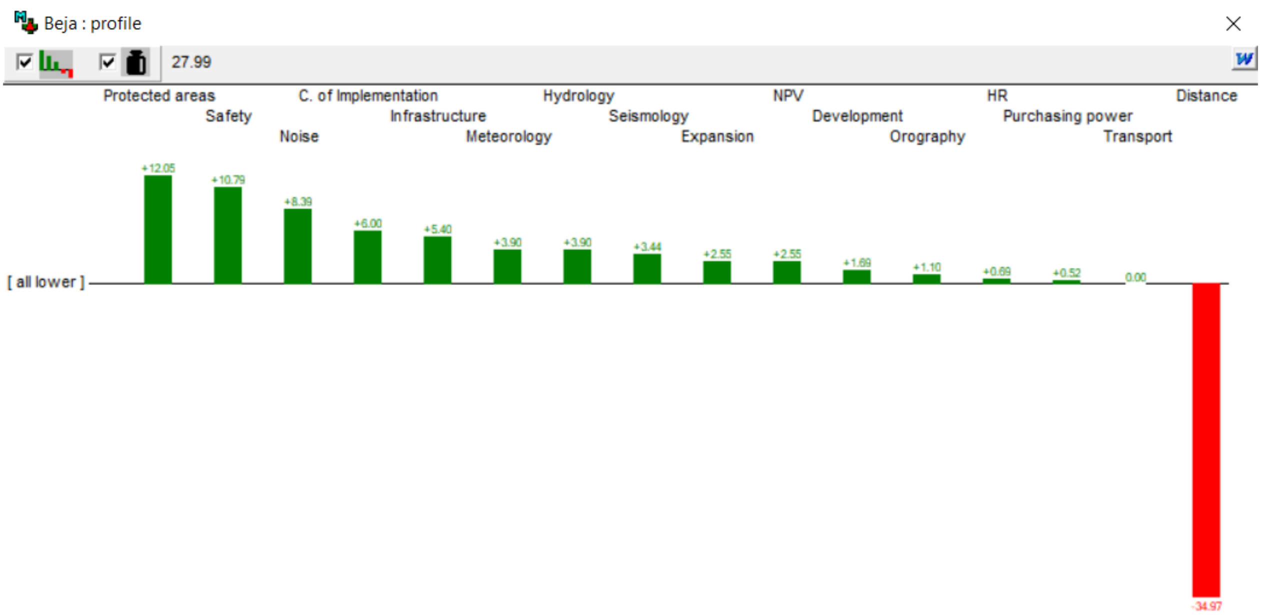


Fig. 50 – Beja weighted scores profile with ordered bars

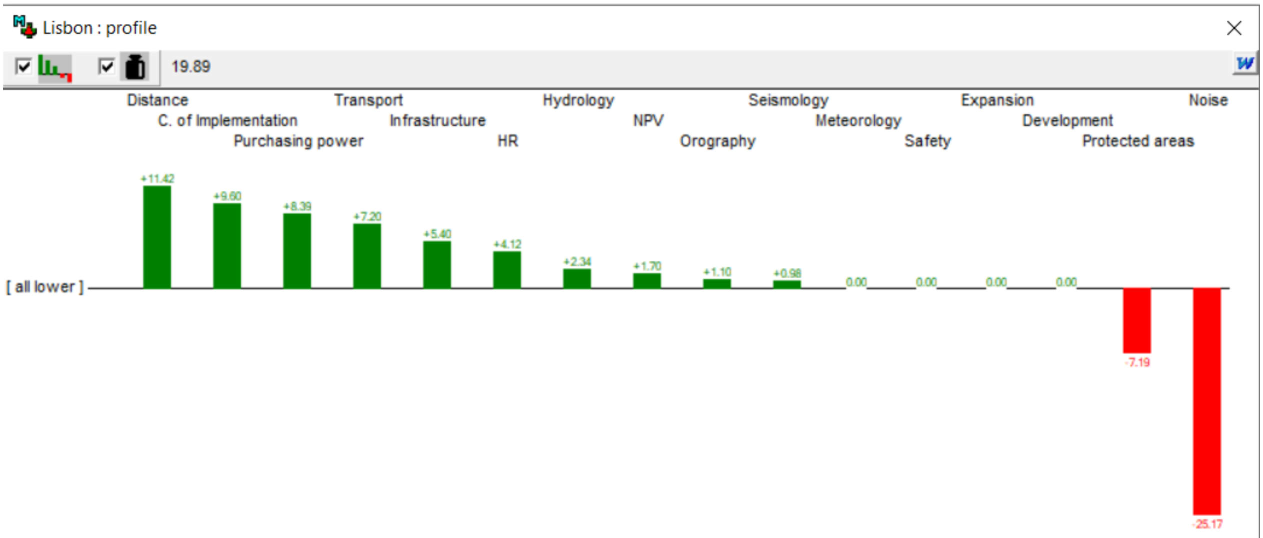


Fig. 51 – Lisbon weighted scores profile with ordered bars

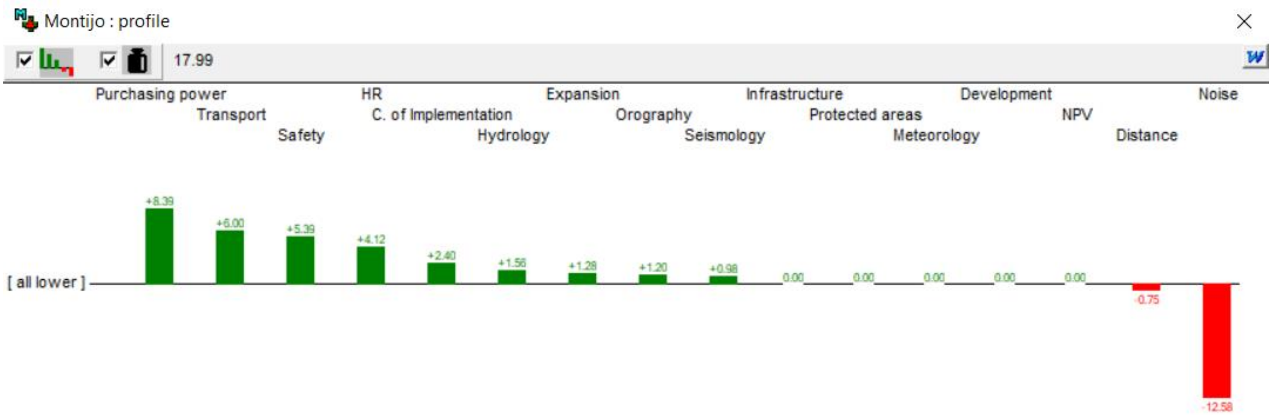


Fig. 52 – Montijo weighted scores profile with ordered bars

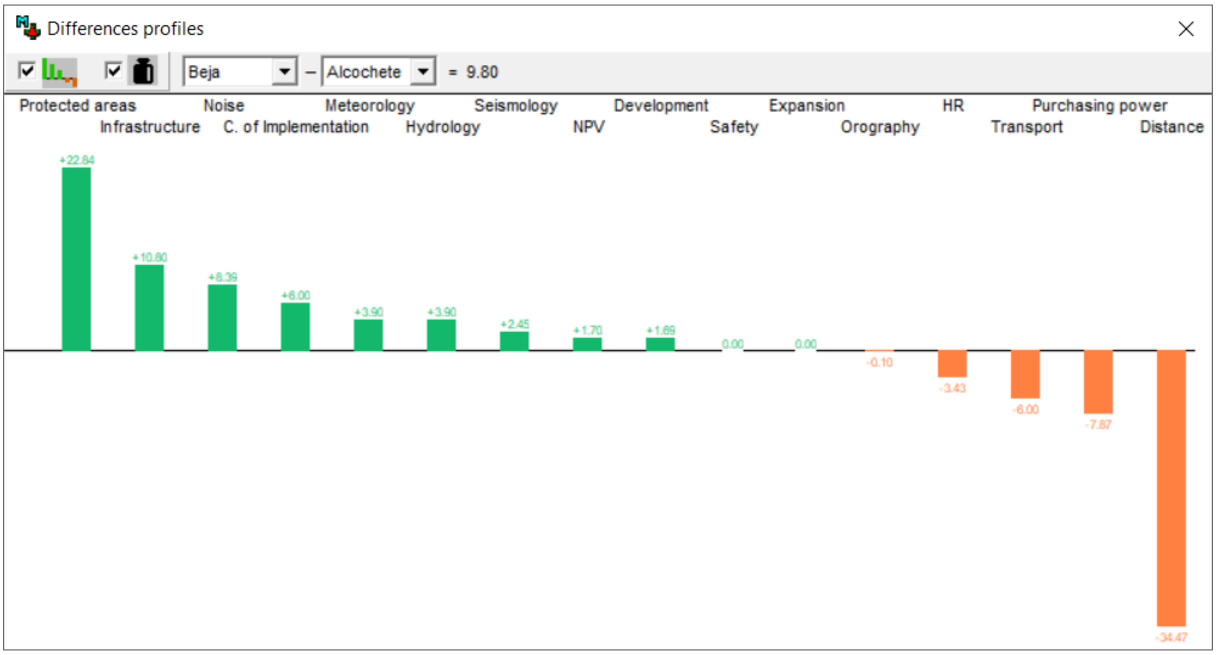


Fig. 53 – Beja-Alcochete weighted difference profile

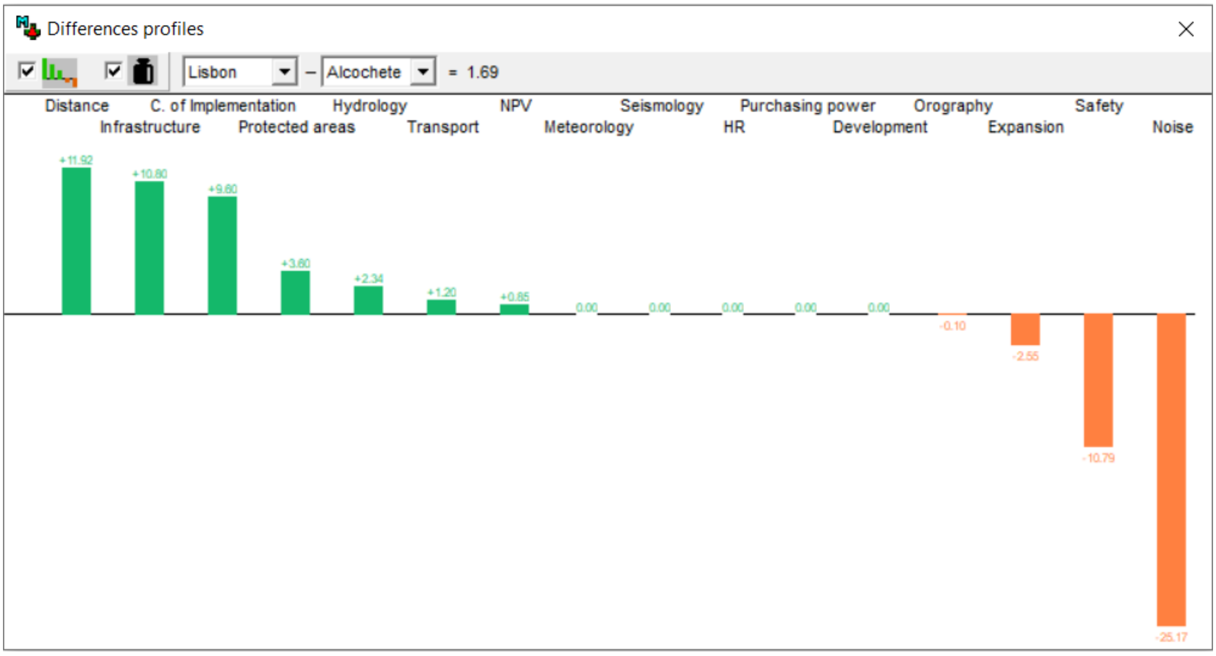


Fig. 54 – Lisbon-Alcochete weighted difference profile

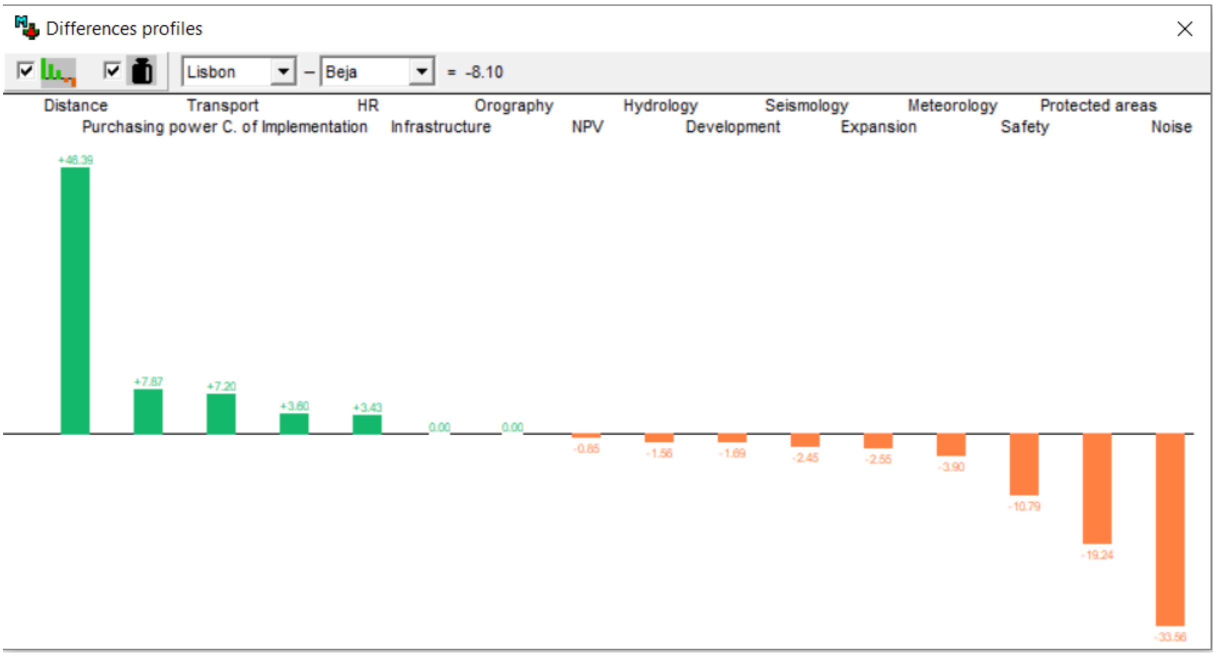


Fig. 55 – Lisbon-Beja weighted difference profile

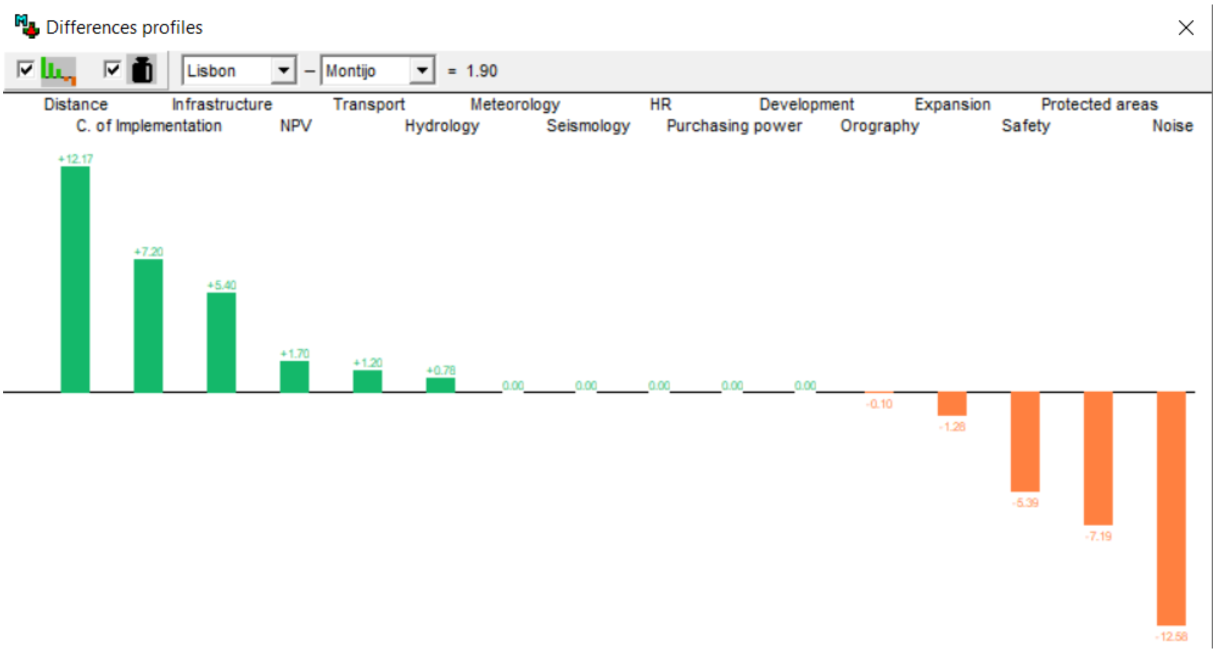


Fig. 56 – Lisbon-Montijo weighted difference profile

Fig. 57 – Montijo-Alcochete weighted difference profile

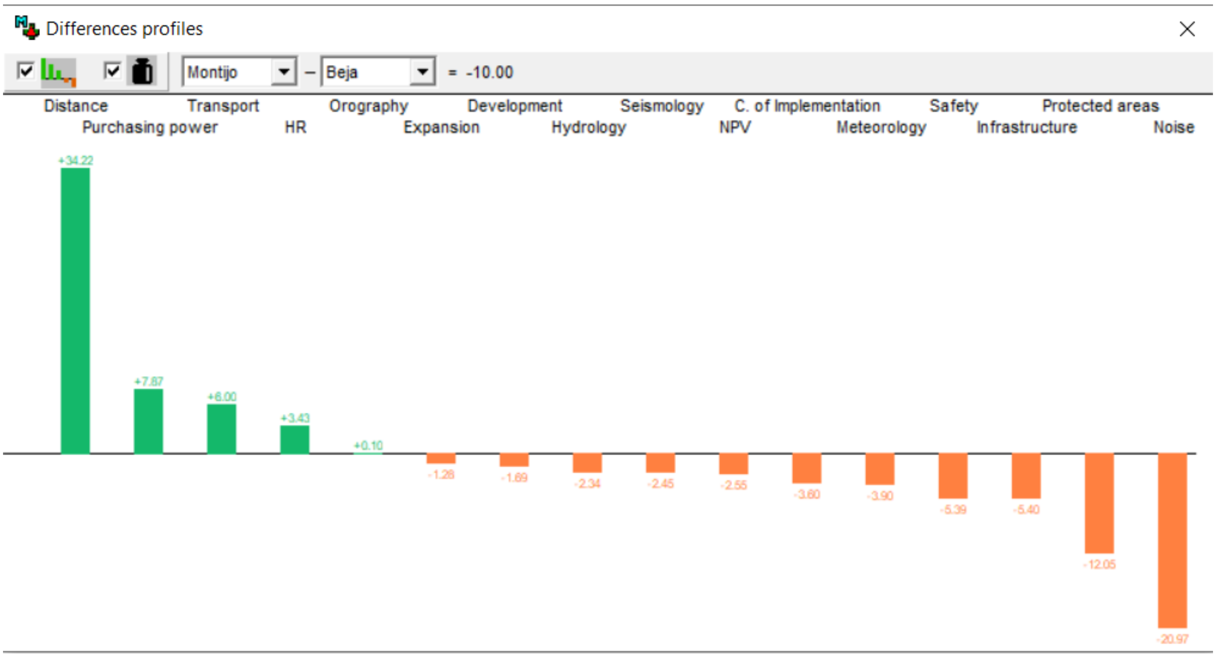


Fig. 58 – Montijo-Beja weighted difference profile

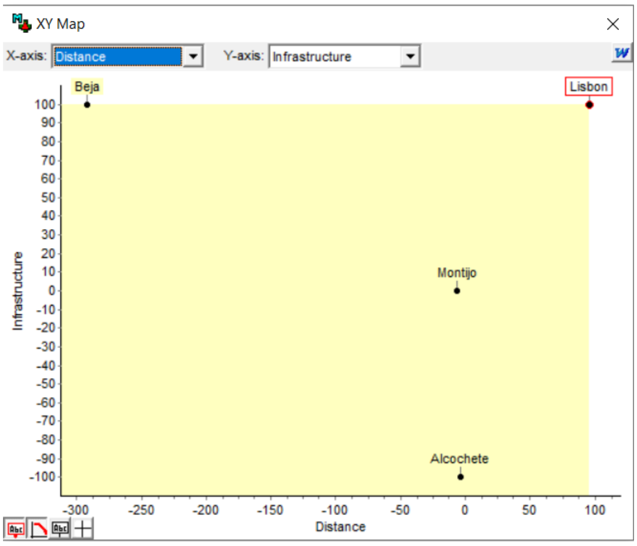


Fig. 59 – XY map of Distance from Lisbon and Infrastructure readiness criteria

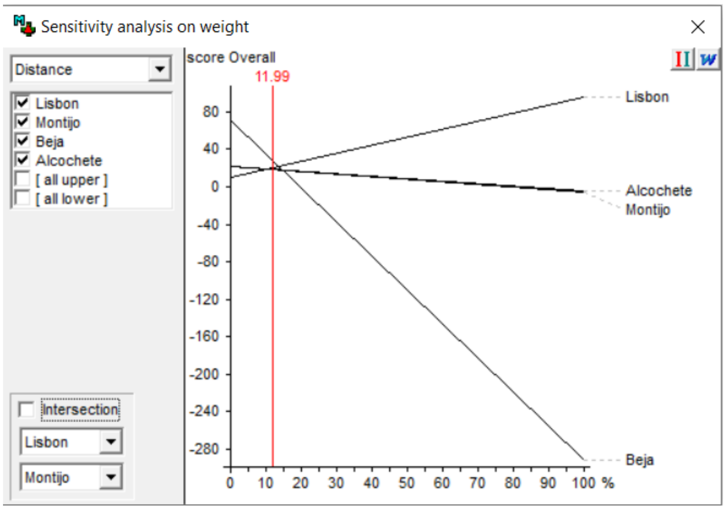


Fig. 60 – Sensitivity analysis on Distance from Lisbon weight

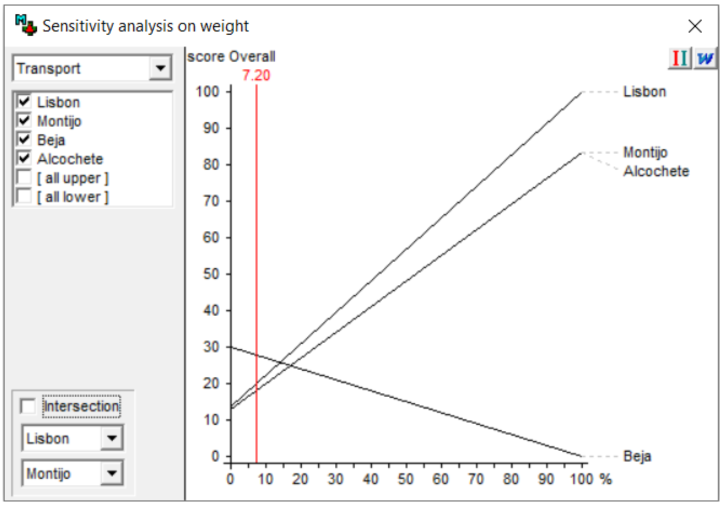


Fig. 61 – Sensitivity analysis on Transport systems weight

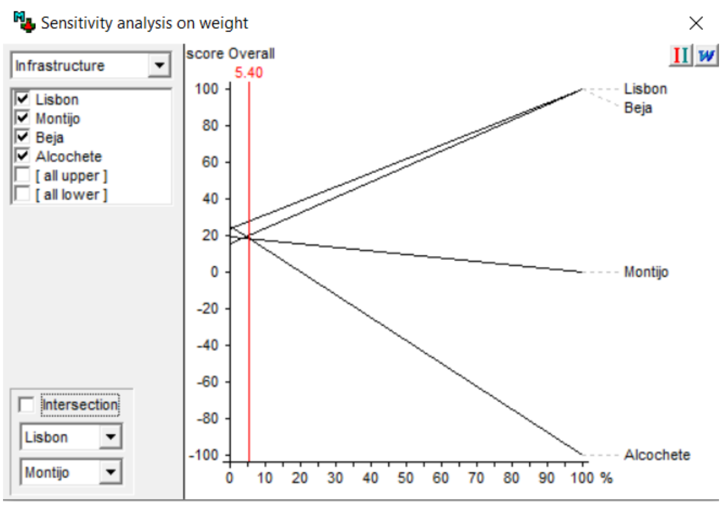


Fig. 62 – Sensitivity analysis on Infrastructure readiness weight

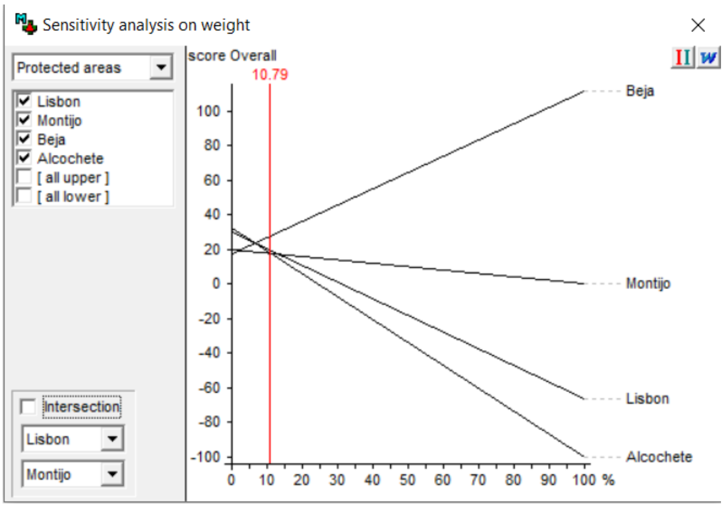


Fig. 63 – Sensitivity analysis on Closeness to protected areas weight

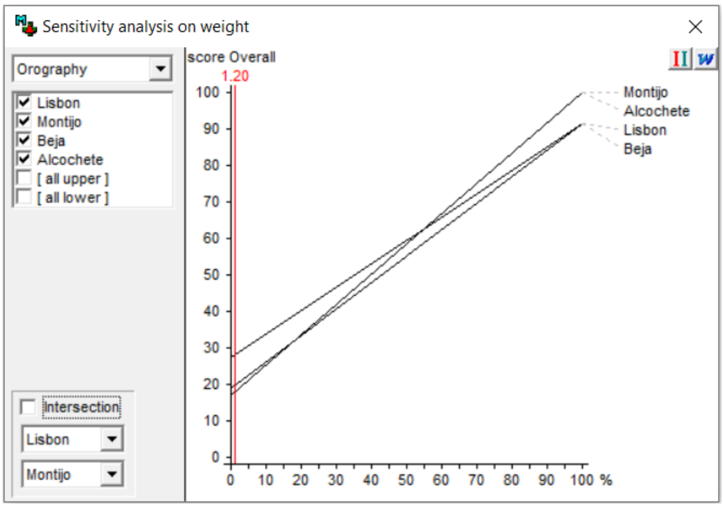


Fig. 64 – Sensitivity analysis on Orography weight

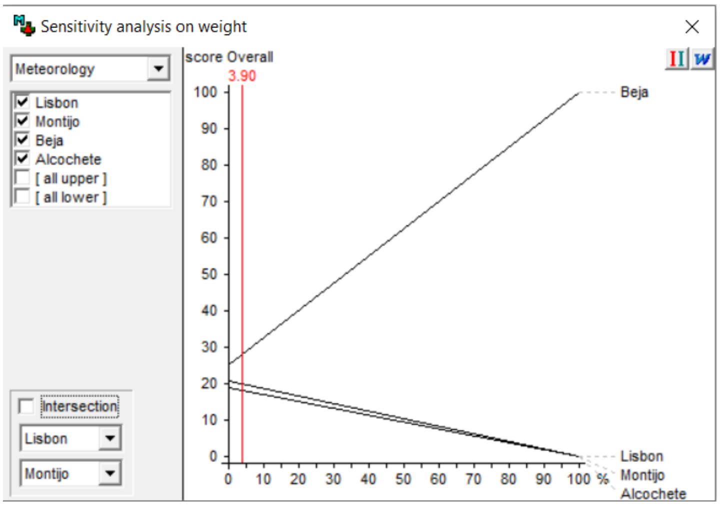


Fig. 65 – Sensitivity analysis on Meteorology weight

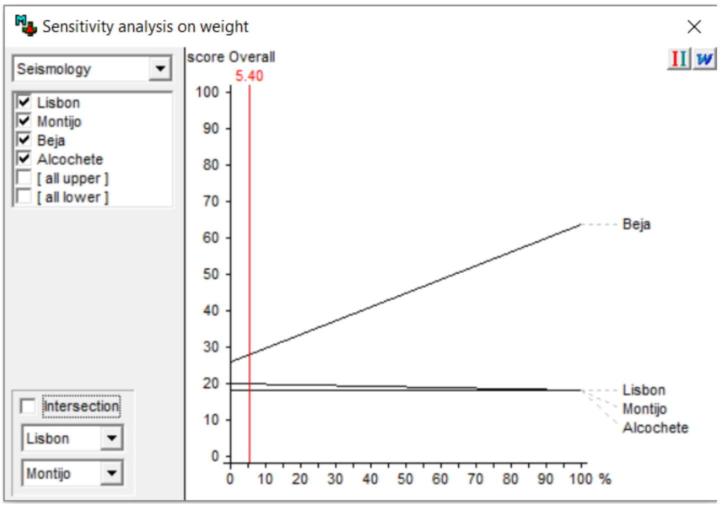


Fig. 66 – Sensitivity analysis on Seismology weight

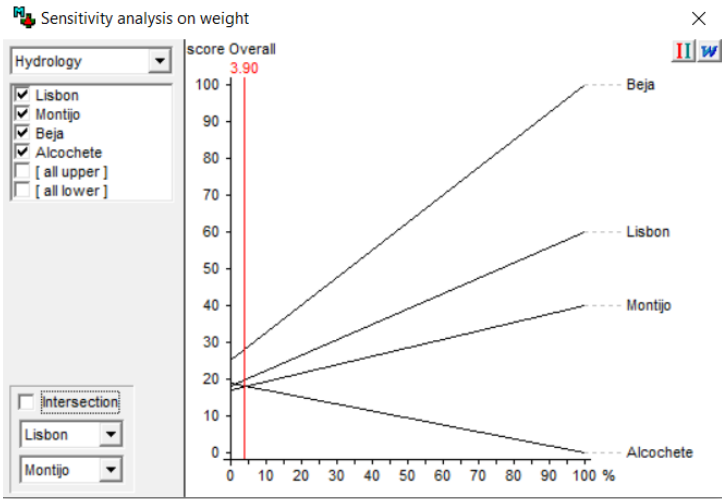


Fig. 67 – Sensitivity analysis on Hydrology weight

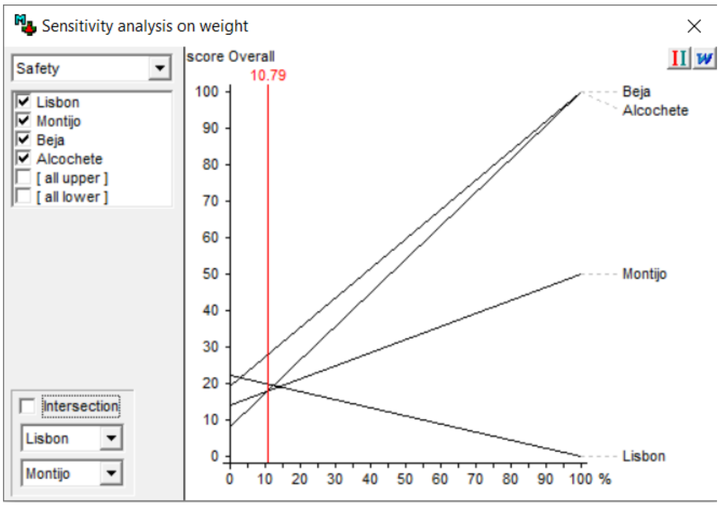


Fig. 68 – Sensitivity analysis on Flight safety weight

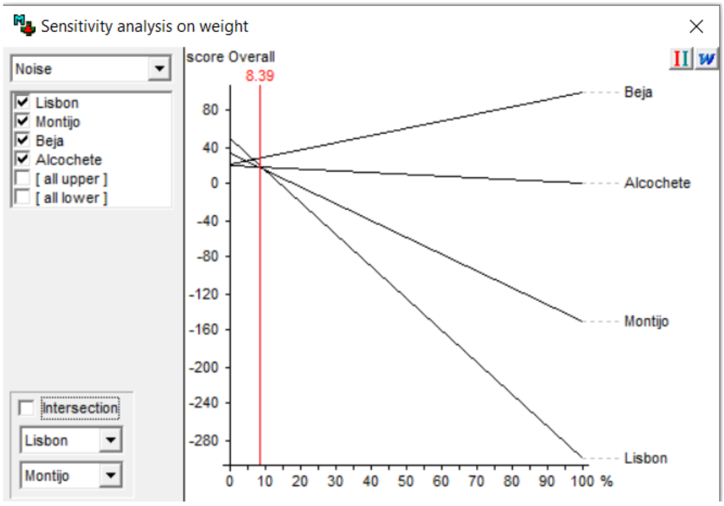


Fig. 69 – Sensitivity analysis on Exposure to noise weight

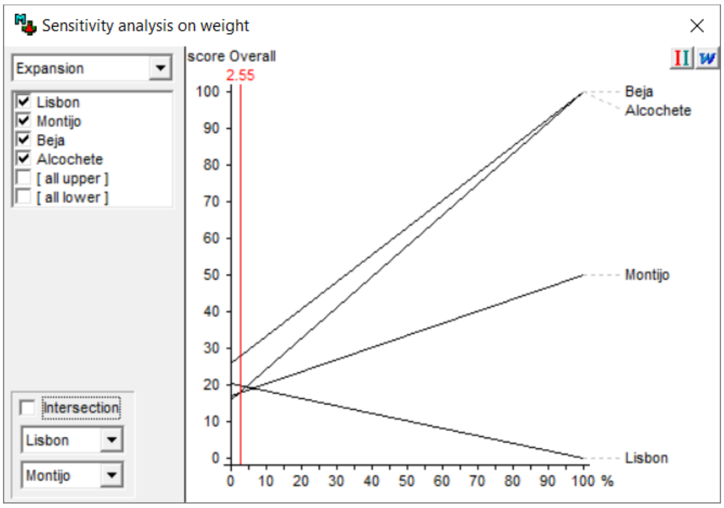


Fig. 70 – Sensitivity analysis on Expansion potential weight

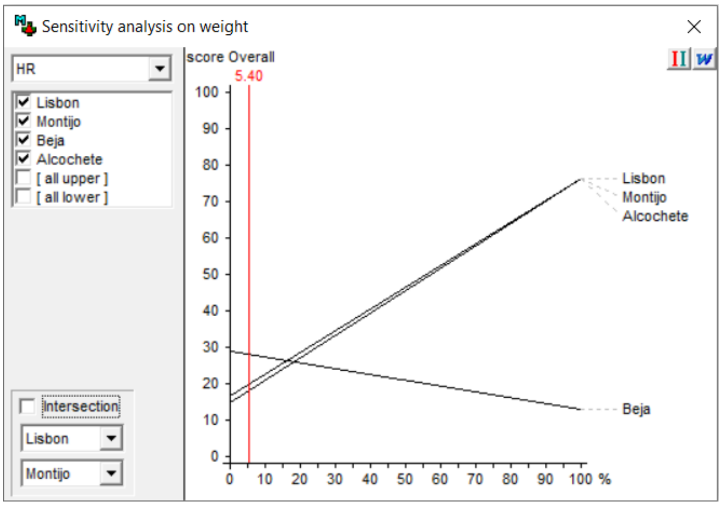


Fig. 71 – Sensitivity analysis on Human resources weight

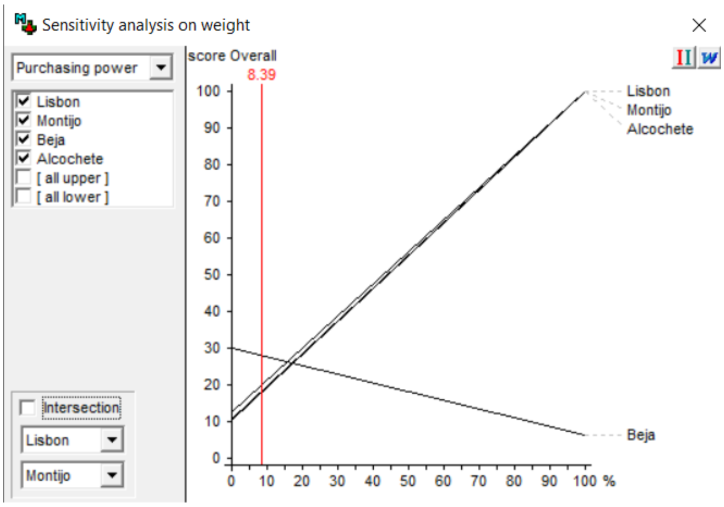


Fig. 72 – Sensitivity analysis on Purchasing power weight

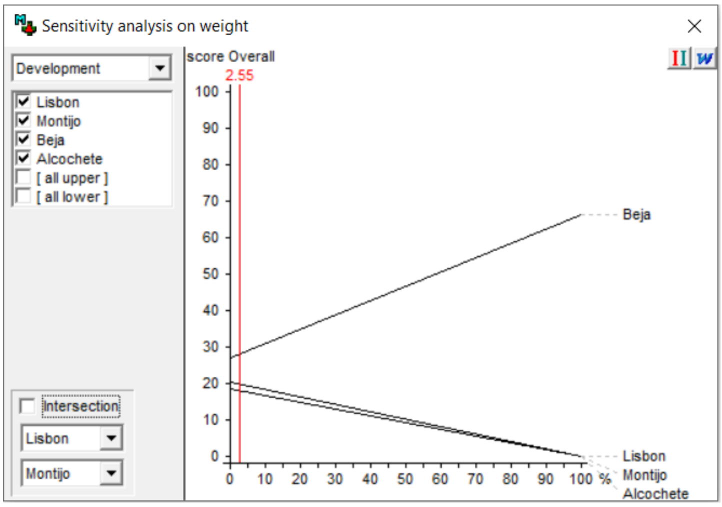


Fig. 73 – Sensitivity analysis on Regional development weight

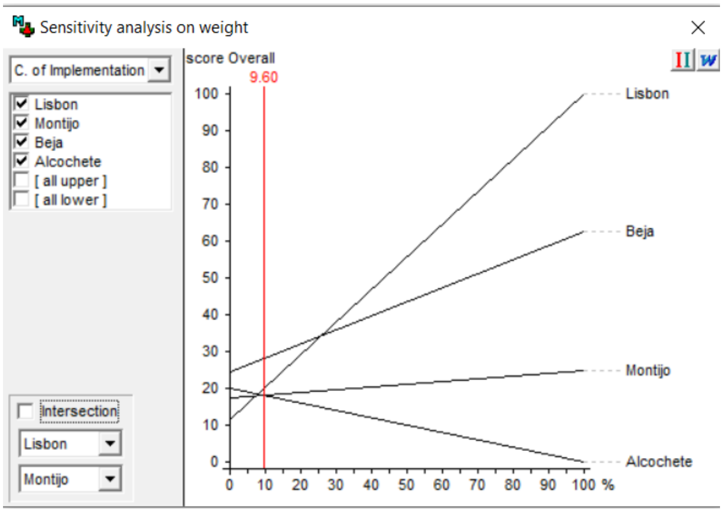


Fig. 74 – Sensitivity analysis on Total cost of implementation weight

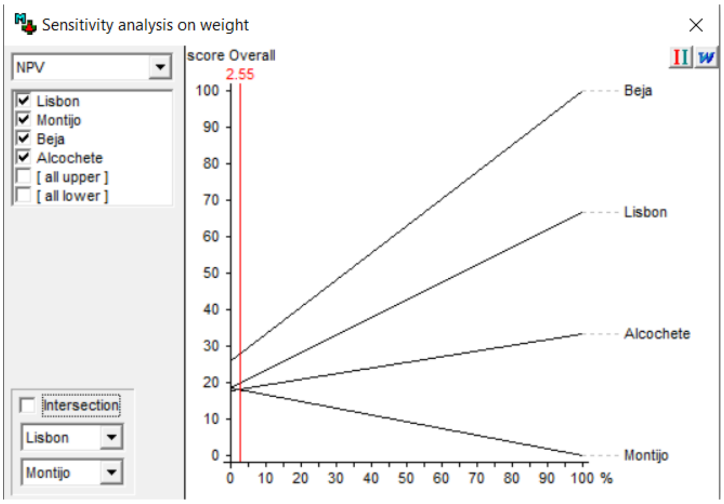


Fig. 75 – Sensitivity analysis on Net Present Value weight

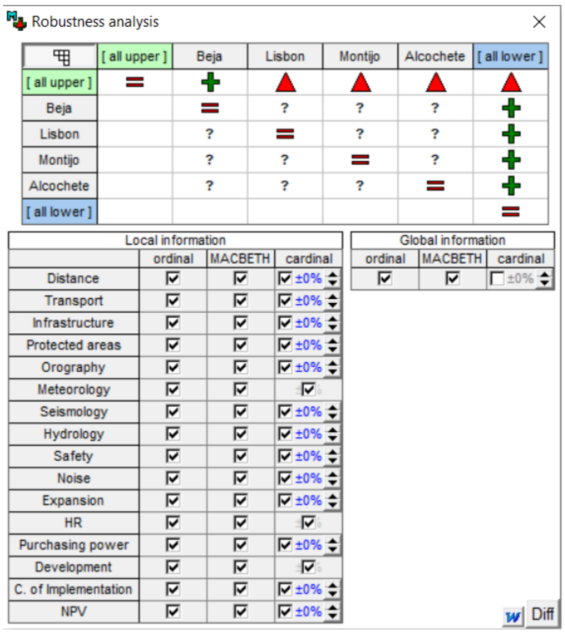


Fig. 76 – Robustness analysis on varying amounts of information without cardinal global information

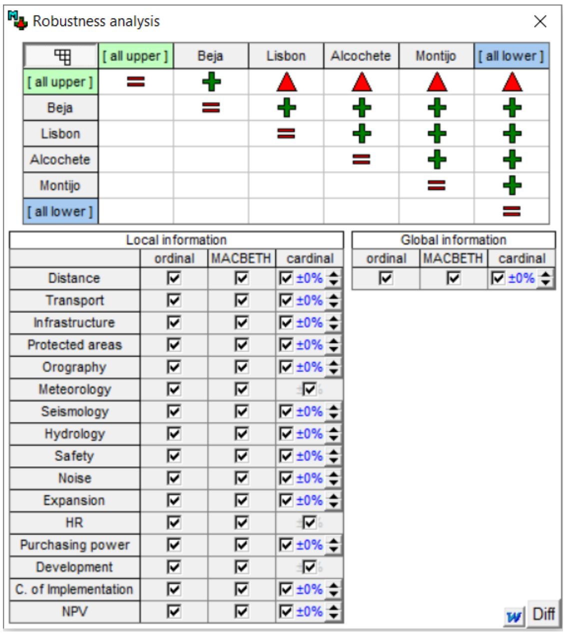


Fig. 77 – Robustness analysis on varying amounts of information with cardinal global information

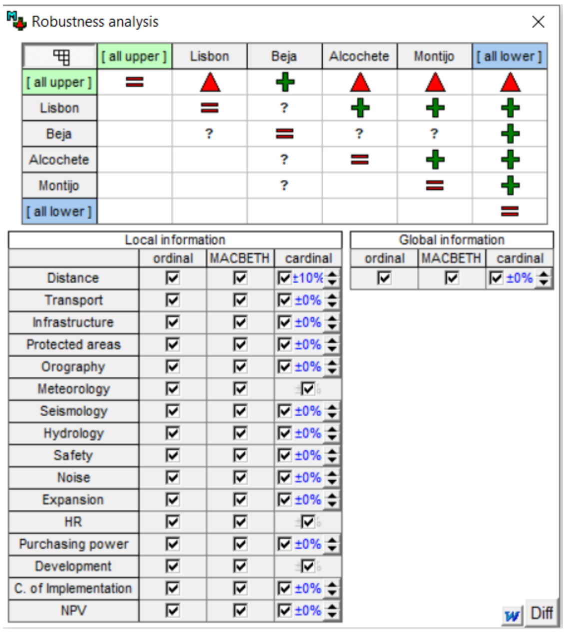


Fig. 78 – Robustness analysis on varying degrees of imprecision about Distance from Lisbon

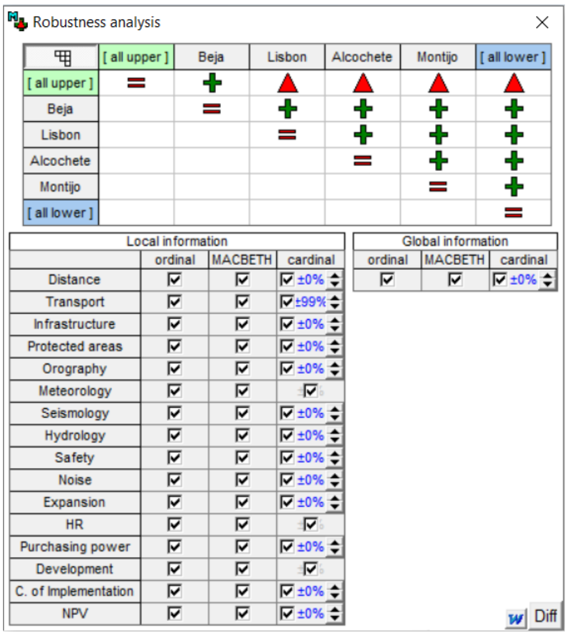


Fig. 79 - Robustness analysis on varying degrees of imprecision about Transport systems

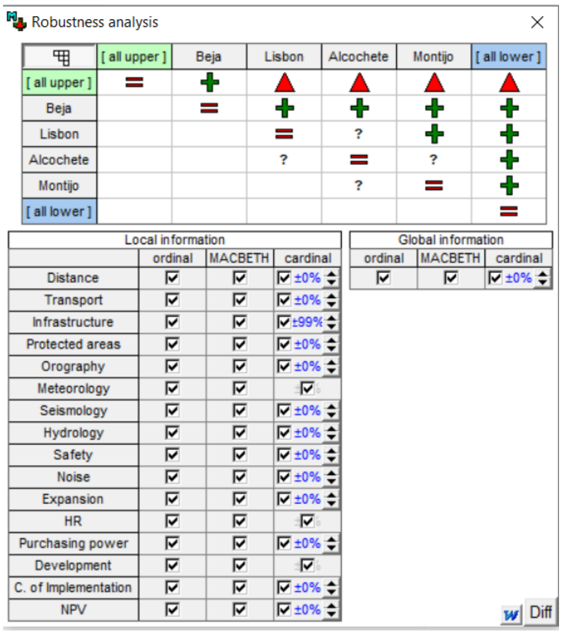


Fig. 80 - Robustness analysis on varying degrees of imprecision about Infrastructure readiness

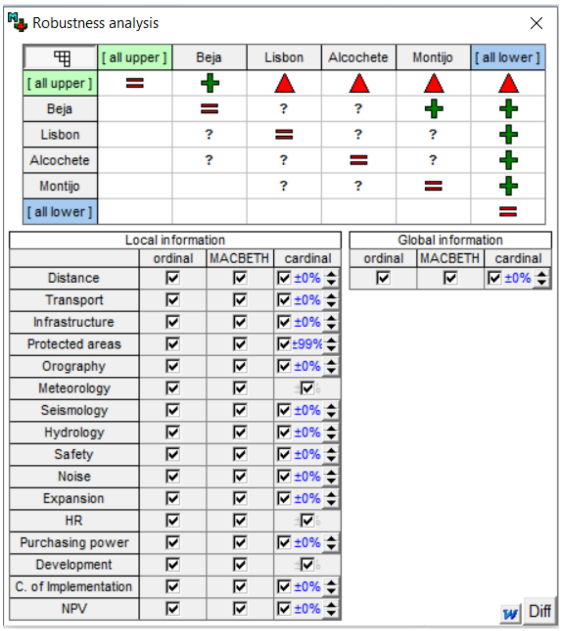


Fig. 81 - Robustness analysis on varying degrees of imprecision about Closeness to protected areas

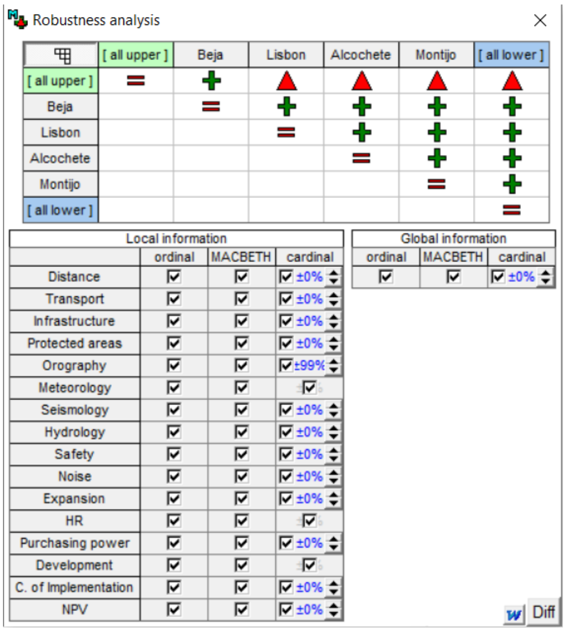


Fig. 82 - Robustness analysis on varying degrees of imprecision about Orography

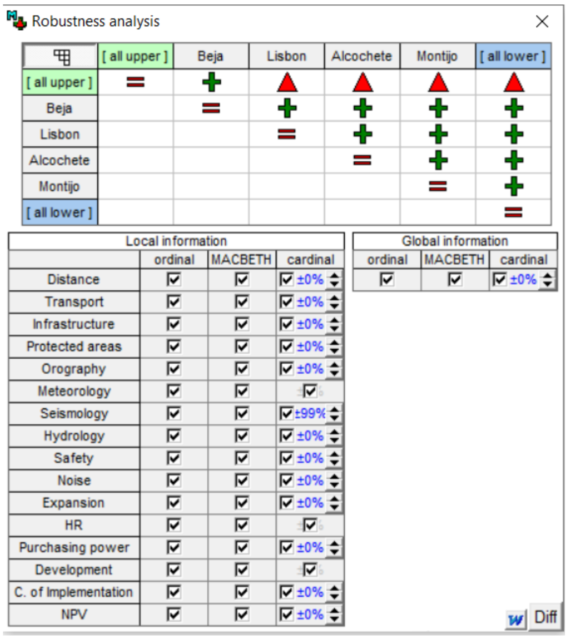


Fig. 83 - Robustness analysis on varying degrees of imprecision about Seismology

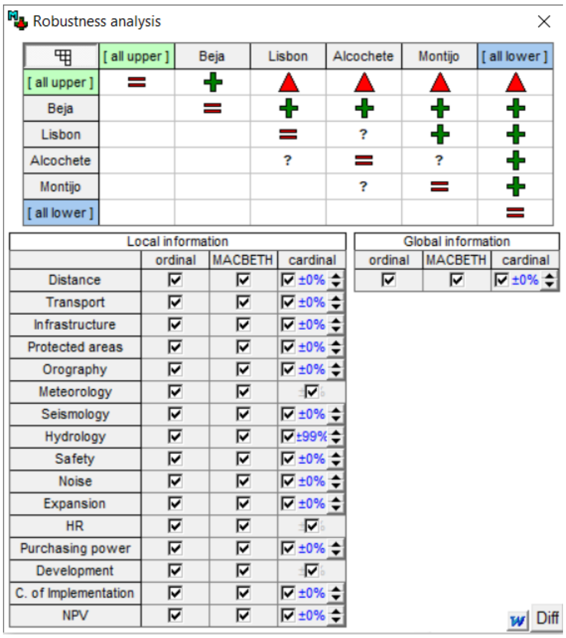


Fig. 84 - Robustness analysis on varying degrees of imprecision about Hydrology

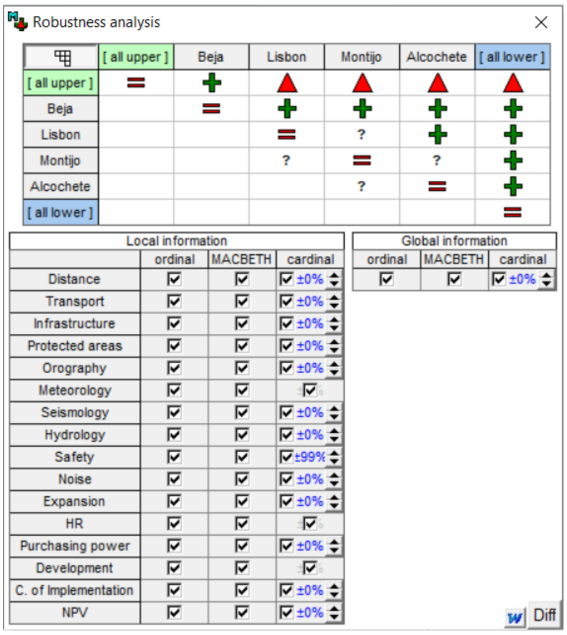


Fig. 85 - Robustness analysis on varying degrees of imprecision about Flight safety

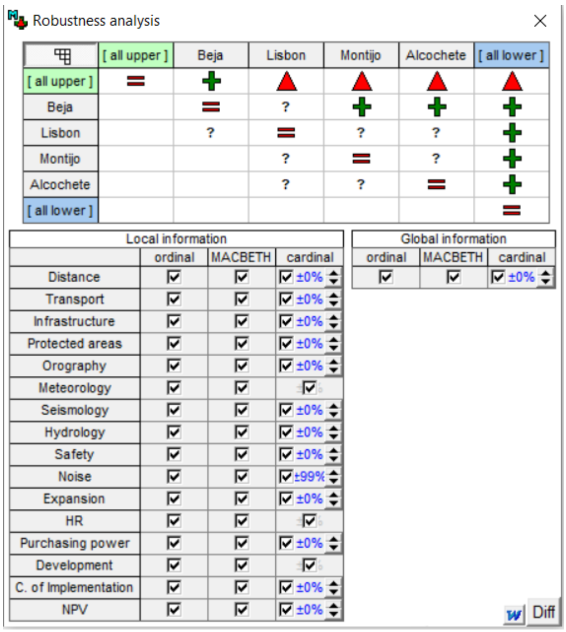


Fig. 86 - Robustness analysis on varying degrees of imprecision about Exposure to noise

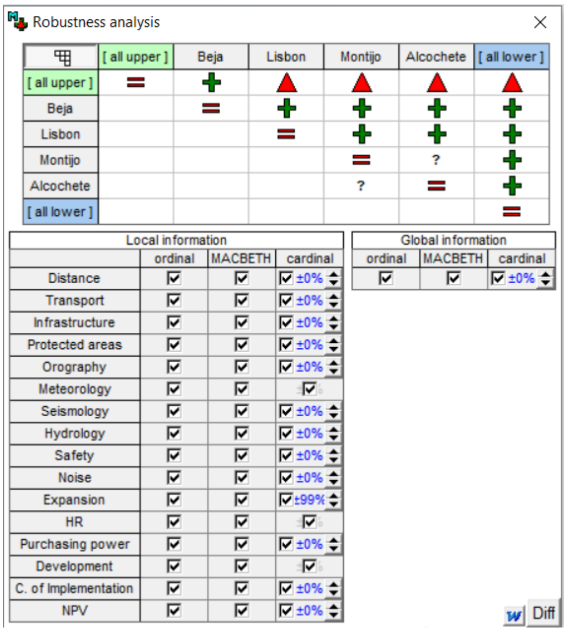


Fig. 87 - Robustness analysis on varying degrees of imprecision about Expansion potential

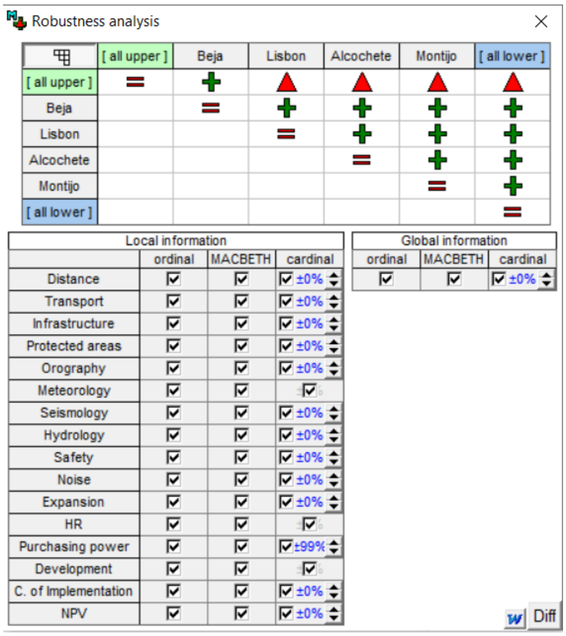


Fig. 88 - Robustness analysis on varying degrees of imprecision about Purchasing power

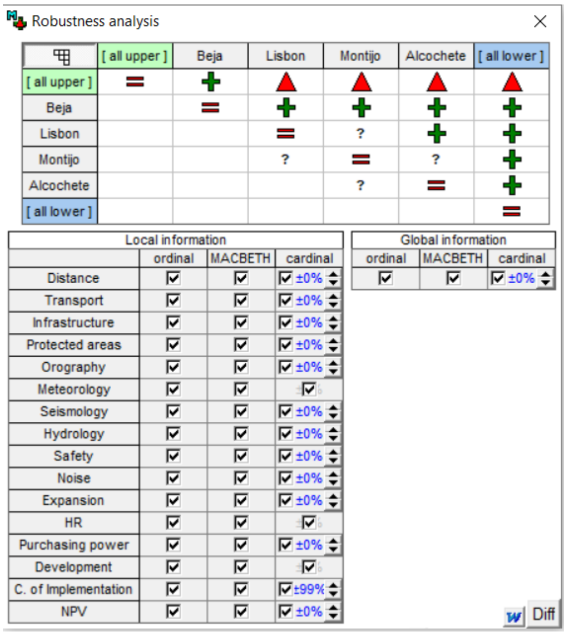


Fig. 89 - Robustness analysis on varying degrees of imprecision about Total cost of implementation

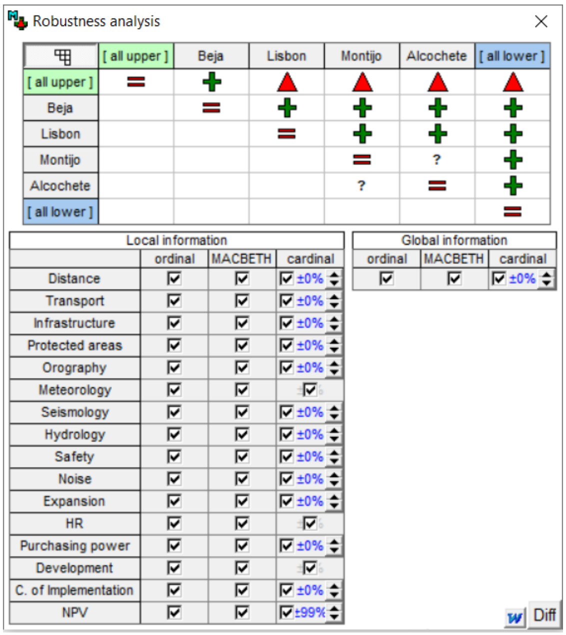


Fig. 90 - Robustness analysis on varying degrees of imprecision about Net Present Value

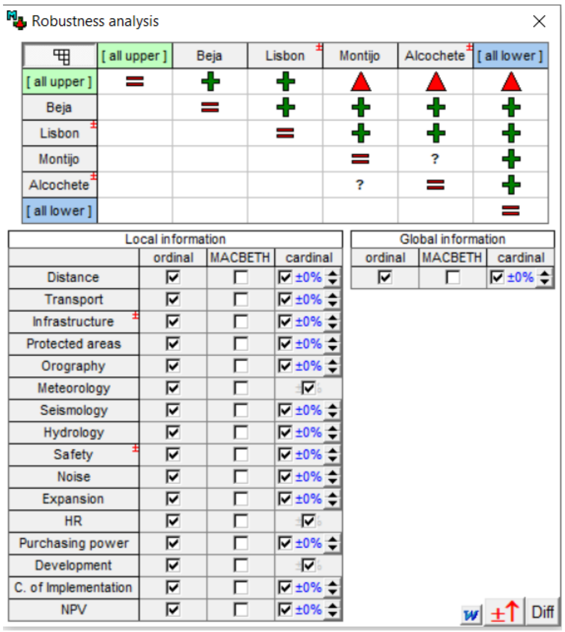


Fig. 91 - Robustness analysis on imprecision about options' performance